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STOCHASTIC SIMULATION ANALYSIS - 2005 (SSA-05)

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PREPARED BY
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13. ABSTRACT (Maximum 200 words)

The Support Force Requirements Analysis - 2005 (SRA-05), recently completed by the US Army Concepts Analysis Agency (CAA), is an important component of the Total Army Analysis - 2005, which estimates the quantities of Army combat support and service support units required for hypothetical warfare contingencies in 2005. The combat outcomes of SRA-05 were estimated by means of the Concepts Evaluation Model (CEM), a fully automated, deterministic, constructive computer model of theater-level warfare that is used extensively for Army studies of force capabilities and requirements. Since 1991 CAA has been developing and testing a stochastic simulation model of theater warfare, based on the CEM, called STOCEM. The objectives of this research are as follows. (1) Using STOCEM, simulate a base case conventional campaign from each of the Korea and Southwest Asia theaters of SRA-05. (2) Compare the results of STOCEM with the deterministic CEM results of SRA-05. This report provides the results, observations, and recommendations of the research.

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STOCHASTIC SIMULATION ANALYSIS - 2005 (SSA-05)

CHAPTER 1

EXECUTIVE SUMMARY

1-1. PROBLEM. The combat outcomes of the Support Force Requirements Analysis - 2005 (SRA-05) were estimated by means of the Concepts Evaluation Model (CEM Reference 1), CAA's deterministic computer model of land and air warfare. However, a deterministic model such as CEM cannot provide estimates of the variability and confidence intervals surrounding the combat outcomes. These estimates are available from a stochastic simulation model, such as the Stochastic CEM (STOCEM).

1-2. BACKGROUND

a. Developed at CAA, the CEM is a low-resolution, two-sided, fully automated, constructive computer model of theater-level warfare that is used extensively for Army studies of force capabilities and requirements. The CEM is one example of an extensively employed theater-level model that remained deterministic due to computer resource constraints.

b. In recent years, however, the availability of fast computers and supercomputers has reduced execution time so much that it is feasible to conduct multiple replications of the theater-level simulations. Beginning in 1991, CAA has initiated a series of analyses (References 2, 3, 4, 5, 6, and 7) to explore the possibilities and performance characteristics of a stochastic simulation model of theater warfare, based on the CEM, called STOCEM. References 3 and 4 examined the feasibility of applying stochastic simulation to Southwest Asia (SWA) and Northeast Asia (NEA, Korea), respectively. References 2, 5, 6, and 7 examined the performance of STOCEM in simulating the 1944 Ardennes Campaign (ARCAS). Selected findings of these studies include the following.

(1) It is feasible to enhance the CEM with stochastic combat model processes and generate multiple replications of stochastic theater-level simulations. The cost in computer resources of executing 10 STOCEM replications is not prohibitive.

(2) The STOCEM can be used to present results with ranges of variability and distributions of outcomes.

(3) The differences in certain outcomes between the stochastic and deterministic CEM simulations are statistically significant.

(4) No single stochastic process in the STOCEM is the greatest contributor to the variability observed in all of the different outcome measures of the STOCEM. Rather, a combination of the stochastic processes of the STOCEM are responsible for the variation in STOCEM outcome measures.

(5) For many of the outcome measures examined, the distribution of results of the STOCEM using deterministic assessment of attrition (that is, using an average combat sample) is significantly different from the distribution of results of the STOCEM using stochastic assessment (that is, using individual replications of the Combat Sample Generator (COSAGE)).

(6) Reference 5 found certain major differences between STOCEM simulation results and history, including "excessively fast forward edge of the battle area (FEBA) movement during the last half of the campaign, excessively high antitank/mortar (AT/M) losses and American and British (US/UK) armored personnel carrier (APC) losses, excessively low artillery losses, and a much larger German ammunition tonnage expenditure" in STOCEM results as compared with Ardennes Campaign Simulation Data Base (ACSDB) records. Reference 5 recommended "key areas of investigation for CEM input and logic modification derived from the ARCAS STOCEM/history comparisons," which were addressed in Reference 6.

(7) Reference 7 identified a mode of STOCEM operation whose STOCEM results are most consistent with the results of deterministic CEM in simulations of the Ardennes Campaign. Essentially this recommended mode consists of (a) calculating the rate of advance in each engagement deterministically, as in CEM and (b) using a single replication of COSAGE for each posture throughout a STOCEM replication, rather than randomly selecting a COSAGE replication for each subsector engagement within STOCEM. Reference 7 recommended the use of a single replication of COSAGE throughout a STOCEM replication in order to obtain greater variability among STOCEM replications. Reference 7 advocated calculating the rates of advance deterministically in order to obtain closer agreement with deterministic CEM, although the stochastic estimate of rates of advance in STOCEM was shown to be more consistent with the historical rates of advance of the Ardennes Campaign.

1-3. PURPOSE AND OBJECTIVES

a. Purpose. The purpose of this research analysis activity (RAA) is to investigate the applicability and utility of STOCEM in simulations of important warfare scenarios from current studies.

b. Objectives

(1) Simulate using STOCEM a base case conventional campaign from each of the NEA and SWA theaters of SRA-05.

(2) Compare the results of STOCEM with the deterministic CEM results of SRA-05.

1-4. SCOPE

a. Sixteen stochastic replications of STOCEM are executed for each situation. Uncertainty in STOCEM outcomes is presented by means of confidence intervals, boxplots, and maximum/ minimum values over the 16 replications.

b. Campaign outcome measures examined include personnel casualties, weapon system losses, ammunition consumption, and progress of the forward edge of the battle area, at 4-day intervals throughout the simulations.

1-5. ASSUMPTION. The inputs to CEM developed for the SRA-05 simulations accurately represent the situation modeled, and are not modified in the analysis reported here.

1-6. LIMITATION. Findings and insights do not necessarily extend to simulations other than the particular SRA-05 scenario used for this study.

1-7. APPROACH

a. Update STOCEM to the version of CEM (CEM IX) used in SRA-05. This includes installing on the Cray computer the BASECEM routines necessary to transform the results of one phase of a STOCEM campaign into the inputs required for the next phase, and to join the separately executed phases of a STOCEM campaign into a single set of STOCEM output reports. Test the updated STOCEM computer routines for errors, and correct any errors that are found.

b. Obtain the CEM simulation inputs of SRA-05 for the west/east (NEA first) scenario. Using these CEM inputs, execute deterministic CEM on the Cray computer to reproduce the SRA-05 base case for each theater. The BASECEM routines are required for the SWA campaign simulation, which consists of four separate CEM phases.

c. Process the individual replications of the COSAGE for each posture for each theater through the Reduction and Linkage Phase 1 (RALPH) program, as required for input to STOCEM.

d. Using the simulation inputs of SRA-05, execute a set of STOCEM simulations for each theater, 16 replications per set.

e. Using graphical and statistical techniques, including boxplots and confidence intervals based on the Fisher/Student *t*-statistic, compare the results of the STOCEM with the CEM base case.

f. Using the simulation inputs of SRA-05, with STOCEM operating in the mode recommended by Reference 7, as described in paragraph 1-2b(7) above, execute a set of partially stochastic STOCEM variation simulations for each theater, 16 replications per set.

g. Using graphical and statistical techniques, compare the results of the STOCEM variation with the STOCEM base case and with the CEM base case, to demonstrate the effects of operating STOCEM in the alternative mode recommended by Reference 7.

1-8. ESSENTIAL ELEMENTS OF ANALYSIS (EEAs)

a. How large is the variability in the results of STOCEM for the SRA-05 scenario?

ANSWER: The variability among the STOCEM replications for each outcome measure at each 4-day time period is indicated by the boxplots in Figures 3-1 to 3-12 and 4-1 to 4-11. In general, the variation among STOCEM replications is largest for FEBA-movement, helicopter-loss, and posture-frequency outcomes, and variation is smallest for losses of Red systems other than helicopters. The variation among STOCEM replications is generally greater in the partial-stochastic mode of STOCEM operation (paragraph 1-2b(7)) than in the STOCEM base case results.

b. To what extent are the results of STOCEM consistent with the CEM results of the SRA-05 scenario?

ANSWER: The consistency of STOCEM with CEM is indicated by Figures 3-13 to 3-25 and 4-12 to 4-24. For most CEM outcome measures, the CEM result is significantly different from STOCEM--that is, outside the 99 percent confidence limits of STOCEM results--for some time periods simulated. The results of the partial-stochastic mode of STOCEM operation (paragraph 1-2b(7)) are more consistent with deterministic CEM than are the STOCEM base case results, as illustrated in Figures 5-1 to 5-25.

1-9. RECOMMENDATIONS

a. Combat Attrition Samples. Reference 7 recommends using a single replication of COSAGE for each posture throughout a STOCEM replication, rather than selecting at random from the COSAGE replications for each subsector engagement within STOCEM. The results in Chapter 4 of this report agree with Reference 7 that using a single replication of COSAGE for each posture throughout a STOCEM replication produces greater variability among STOCEM replications than does the full-stochastic mode of operating STOCEM. If greater variability among STOCEM replications is desirable, then using a single replication of COSAGE for each posture throughout a STOCEM replication is a means of increasing that variability. This mode of STOCEM operation implies a selection from among the replications of COSAGE is made for each posture before executing STOCEM. In this approach, it is appropriate to select from among the replications of COSAGE *without replacement*, so that all the COSAGE replications for a given posture are used for the STOCEM replications before any COSAGE replications are repeated.

b. Rates of Advance. For a given combat engagement, the expected value of the STOCEM rate of advance calculations is not necessarily the same as the rate of advance calculated in deterministic CEM, as noted in Reference 7. Hence, to make STOCEM more consistent with CEM, although possibly less consistent with history, the stochastic calculation of rates of advance can be deactivated in STOCEM. Figures 5-12 and 5-24 show that STOCEM with the deterministic rate of advance produces FEBA movement more consistent with CEM than does full-stochastic STOCEM.

c. STOCEM on Workstations. Each replication of STOCEM of the 140-day NEA campaign takes more than 24 minutes to execute on the Cray computer. The run length gives these runs a low priority on the Cray system, so the NEA runs sometimes waited weeks before they were executed. The time spent waiting for the NEA simulations to be executed on the Cray system would not be acceptable to many studies. STOCEM should be installed on a Unix workstation at CAA, provided that FORTRAN-callable routines are available for drawing random numbers from uniform and beta distributions.

CHAPTER 2

STUDY APPROACH AND METHODOLOGY

2-1. THE STOCHASTIC CONCEPTS EVALUATION MODEL (STOCEM)

a. The CEM, developed at CAA, is a two-sided, fully automated, constructive computer simulation of theater-level warfare that is used extensively for Army analyses of force capabilities, of operational plans, and of requirements for support force structure, ammunition by type, trained personnel, and equipment replacements. The resolution of CEM maneuver units is to brigade on the Blue side, division on the Red side. The CEM is a frequently used theater-level model that for many years remained deterministic, rather than stochastic, because of computer resource constraints.

b. In recent years, the availability of fast computers and supercomputers has reduced execution time so much that it is feasible to conduct multiple replications of the theater-level simulations. Beginning in 1991, CAA has initiated a series of studies (References 2, 3, 4, 5, 6, and 7) to explore the possibilities and performance characteristics of a stochastic simulation model of theater warfare, based on the CEM, called STOCEM. The STOCEM permits a user, by input, to treat each of the following CEM processes as either deterministic or stochastic.

(1) Decision Thresholds. Decision thresholds are the friendly/enemy force ratio thresholds used in the CEM to make decisions at army, corps, and division headquarters, such as mission, commitment or reconstitution of reserves, assignment of sector boundaries to subordinates, and allocation to subordinates of general support artillery and close air support. In the deterministic mode, the force ratio is compared with a threshold, T, that is input. In the stochastic mode, the force ratio is compared with a threshold, τ, that is drawn from a beta distribution that is controlled by the input parameters a and b as follows.

(a) If $a \neq b$, then the threshold τ is drawn from a skewed beta distribution:

$$\tau = T\,[a + (b^2 - a^2)\,\mathrm{RNBETA}(a, b) / a] / b$$

where τ = the stochastically obtained decision threshold value,

T = the input value used as the mean of the distribution,

RNBETA(a,b) is a computer routine, controlled by parameters a and b, for drawing random numbers from a beta distribution on the interval (0, 1).

$\mathrm{Variance}(\tau) = T^2 (b - a)^2 / [ab\,(a+b+1)]$,

Range of τ is (aT / b, bT / a).

(b) If a = b, then the threshold τ is drawn from a symmetric beta distribution:

$$\tau = 2\ T\ RNBETA(a, b)$$

where T = the input value used as the mean of the distribution,

Variance(τ) = $T^2 / (2a+1)$,

Range of τ is (0, 2T)

(2) Hasty/Prepared Defense Threshold. In the deterministic mode, the recent movement of the FEBA in a sector is compared with an input threshold H to determine whether a defender in the sector fights from "prepared" or "hasty" defenses. In the stochastic mode, the FEBA movement is compared with a threshold value, θ , drawn from a beta distribution controlled by the input parameters a, b, and mean H, as defined in the preceding paragraph.

(3) Combat Samples. In the deterministic mode, the combat sample used for all assessments of attrition is an average of the replications of COSAGE for the appropriate posture. In the stochastic mode, an individual replication of COSAGE for the appropriate posture is randomly selected for each subsector engagement as the combat sample to be used in assessing combat attrition.

(4) Disposition of Losses

(a) In the deterministic mode, for each subsector engagement, the quantity of combat-damaged vehicles of a particular type that are destroyed rather than repairable; the quantity of repairable damaged vehicles that must be abandoned because of adverse FEBA movement; the quantities of combat casualties of personnel that are wounded, of wounded that require hospitalization, and of hospitalized wounded that require evacuation from theater are calculated by multiplying the losses by an input fraction P.

(b) In the stochastic mode, the disposition of combat-damaged tanks is treated stochastically as a binomial distribution. For each tank that is damaged in combat a random number R is drawn from the uniform distribution U(0, 1). The randomly drawn number, R, is then compared to the input probability, P, of catastrophic kill (K-kill) given combat damage, for the shooter-target combination. If R is greater than P, the damaged tank is classified as repairable; otherwise, the tank is permanently destroyed. The same technique is applied to determine stochastically whether repairable damaged vehicles are recovered or abandoned because of an advancing enemy, except that the probability, P, of abandonment depends on the rate of FEBA displacement. The disposition decisions for other damaged vehicles -- light armor, helicopters, and artillery -- and for personnel casualties are made stochastically the same way.

(5) FEBA Movement. The STOCEM provides users the option of stochastic modeling of displacement of the FEBA for each subsector engagement.

(a) In the deterministic mode, the attacker's rate of advance in a subsector is calculated by interpolation on an input table based on terrain type, posture, and a factor called

Defender's Advantage that is derived from the fractional exchange ratio in the engagement. (Reference 5, pp 1-165) as follows:

$$\text{Defender's Advantage } \alpha = 0.5 \log_e \{[1 - (A_r / A_i)^2] / [1 - (D_r / D_i)^2]\}$$

where A_r= attacker's combat worth remaining after the engagement,

A_i= attacker's combat worth at the start of the engagement,

D_r= defender's combat worth remaining after the engagement,

D_i= defender's combat worth at the start of the engagement.

(b) A cumulative frequency function F for the five movement rate class intervals (very fast, fast, moderate, slow, very slow) has been constructed as a function of terrain type, posture, and Defender's Advantage, derived from historical battles by R. Helmbold (Reference 8). Figure 2-1 depicts how the probabilities of the five movement rate classes are related to the value of Defender's Advantage for the engagement. In Figure 2-1, the movement rate classes for a given value, α , of Defender's Advantage have the probabilities shown (in percent) by the vertical distances between the curves above the value α . In the STOCEM stochastic mode, for a particular engagement, the Defender's Advantage α is calculated, and a random number R is drawn from the uniform distribution U(0, 100). The inverse of F, $F^{-1}(R)$, yields a movement rate class. That is, the movement rate class is determined from Figure 2-1 by which vertical interval above α , on the horizontal axis, contains R. The outcome movement rate is randomly selected using a uniform distribution within the boundaries of the selected movement rate class interval.

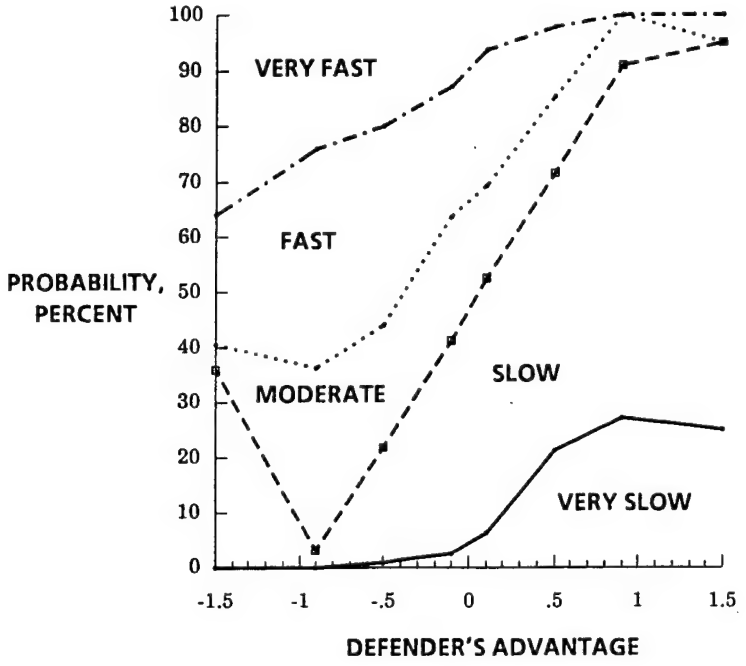

Figure 2-1. Probability of Movement Rate Class vs Defender's Advantage

2-2. ANALYSIS APPROACH

a. The STOCEM currently operates only on an offsite Cray supercomputer, while deterministic CEM is normally executed for studies on Unix workstations at CAA. In order to conduct this analysis, it was necessary to update STOCEM to the version (CEM IX) used in SRA-05. This required a number of STOCEM runs for testing and debugging. The updating of STOCEM also entailed the installation on the Cray supercomputer of the BASECEM programs required to connect the SWA battle phases that are separate CEM runs.

b. Using the updated STOCEM, we established a base case for the campaign. We obtained a full set of CEM input data for SRA-05 conventional campaigns in the NEA and SWA theaters, as well as selected CEM output files of these simulations for comparison. With all available processes in STOCEM set to the stochastic mode and the SRA-05 input data for each theater, we executed 16 replications of the STOCEM. The stochastic assessment of combat attrition was modeled in the STOCEM by drawing from the individual replications of COSAGE for the appropriate posture for each subsector engagement. To make the STOCEM inputs as consistent as possible with those of the deterministic CEM, the mean value of the distribution of each of the stochastic processes of the STOCEM was set to the input value that was used in the deterministic CEM. (The stochastic rate-of-advance estimate in STOCEM does not have a mean value as input; the input maximum and minimum speeds for each movement category are the same as CEM's.) For the commanders' decision thresholds and hasty/prepared defense decision processes, the standard deviation was set by input at 1/10 of the input mean value.

c. Boxplots were constructed from the STOCEM results for each theater, using SPSS 6.1 for Windows software. Figures 3-1 to 3-12 and 4-1 to 4-11 show a separate boxplot for every 4-day interval of the simulation for each selected outcome measure. These boxplots have the following characteristics, as seen in the example in Figure 2-2.

- The boxes contain the 50 percent of data between the 25th and 75th percentiles of STOCEM results.
  - * The top and bottom of each box are the quartile values of the STOCEM replications, so the (vertical) box-length is the interquartile range.
- The line across each box indicates the median of the STOCEM replications.
- "Whiskers" extend from each box to the highest and lowest values, excluding outliers.
- Circles denote "outliers," which are between 1.5 and 3 box-lengths from the box.
- Asterisks denote "extreme values," which are more than 3 box-lengths from the box.

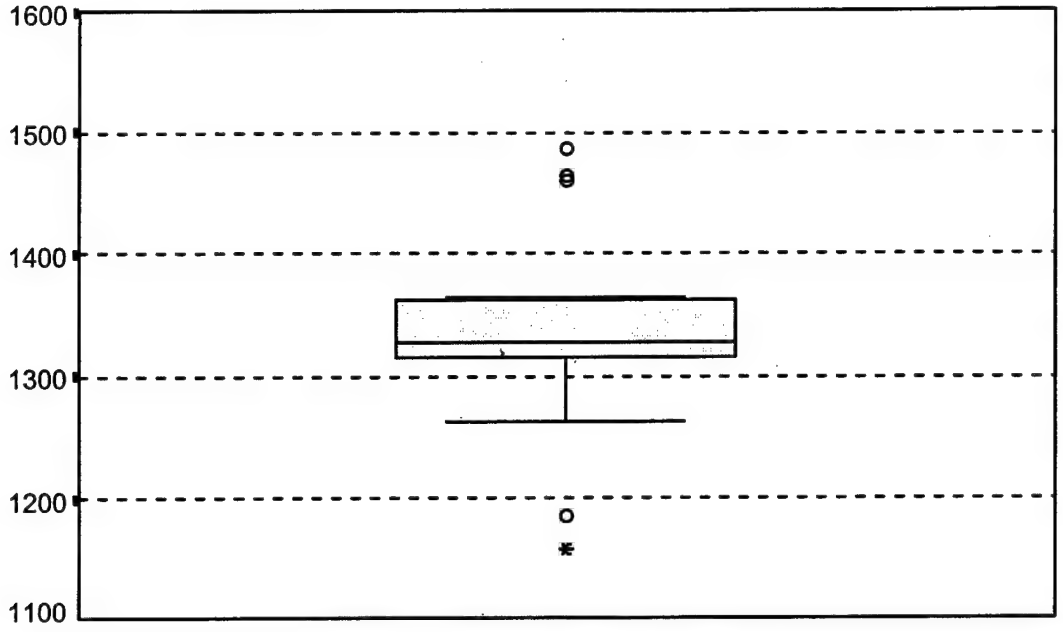

Figure 2-2. Sample Boxplot

d. Using Microsoft Excel 5.0, we constructed plots of confidence intervals about the mean for selected outcome measures of effectiveness (MOE). These confidence intervals are based on the Student-Fisher *t*-statistic for the 16 values of an outcome measure obtained from the STOCEM replications for each 4-day cycle, as follows.

$$\text{Confidence limit} = \bar{X} \pm 2.947\, s / \sqrt{16}$$

where:

$\bar{X}$ = the sample mean;

2.947 is the (Student-Fisher) *t*-statistic for 99 percent confidence with 15 degrees of freedom;

s = the sample standard deviation, whose square is the sample variance s^2:

$$s^2 = \sum_i (X_i - \bar{X})^2 / 15.$$

If the distribution of outcomes from the replications of STOCEM for a particular 4-day interval satisfies the applicability conditions of the Student/Fisher t-statistic, then these displays depict confidence intervals of 99 percent about the mean of the distributions.

e. The STOCEM Investigation of COSAGE Sampling (SICS, Ref. 7), completed at CAA in June 1997, recommended an improved way of operating STOCEM:

(1) Calculate rates of advance deterministically, as in CEM. That is, deactivate STOCEM's stochastic estimation of rates of advance.

(2) Use data from a single replication of each COSAGE posture throughout a replication of STOCEM. The COSAGE replication would be selected at random before executing STOCEM.

Using this operating mode, another set of 16 STOCEM replications was executed for each theater of SRA-05. For the SWA campaign, only the first 40 days (Phase 1) were executed. Confidence intervals of 99 percent about the mean were prepared for selected MOE, using the (Student-Fisher) *t*-statistic as in paragraph d above. These confidence intervals are displayed in comparison with those of the STOCEM base case in Chapter 5.

2-3. OUTCOME MEASURES. The campaign simulation outcome MOEs used in our analysis were chosen to focus on those outcomes that are relevant to SRA-05 issues. The selected MOEs include measures of FEBA movement, attrition, and ammunition expenditures. The following specific campaign outcome measures, available at 4-day intervals, are included in the analysis.

a. Map displays, produced by means of the Terrain Evaluation Module (TEM), that show the location of the average FEBA obtained from a set of STOCEM replications for a particular day of the NEA campaign.

b. Cumulative Blue (US and Allied) personnel permanent casualties (dead, captured, missing, or evacuated from theater).

c. Cumulative permanent losses of Blue tanks. Permanent losses include repairable damaged vehicles that are abandoned because of a rapidly advancing enemy.

d. Cumulative permanent losses of Red (enemy) tanks.

e. Cumulative permanent losses of Blue artillery weapons.

f. Cumulative permanent losses of Red artillery weapons.

g. Cumulative permanent losses of Blue light armor weapons.

h. Cumulative permanent losses of Red light armor weapons.

i. Cumulative permanent losses of Blue combat helicopters.

j. Cumulative permanent losses of Red combat helicopters.

k. Cumulative Blue ammunition consumed (tons).

l. Percentage of the Blue forces attacking.

2-4. ORGANIZATION OF REPORT. Chapter 3 shows the STOCEM Korea base case and compares it with the results of the SRA-05 CEM simulation. Chapter 4 shows the STOCEM Southwest Asia base case and compares it with the results of the SRA-05 CEM simulation. Chapter 5 provides the results of operating STOCEM for both SRA-05 theaters in the mode suggested by the SICS analysis (Reference 7), in comparison with the base case STOCEM simulations.

CHAPTER 3

STOCEM BASE CASE, NORTHEAST ASIA

3-1. SIMULATION CHARACTERISTICS. The STOCEM base case simulation results presented in this chapter consist of 16 replications of the STOCEM, updated to Version IX of CEM. STOCEM inputs are the same as the CEM inputs of SRA-05 (NEA first scenario).

3-2. STOCEM RESULTS DISPLAYED AS BOXPLOTS

a. Boxplots offer a means of displaying the variability among the 16 replications of STOCEM. Our boxplot charts contain a boxplot for every 4-day period simulated in STOCEM. The boxplots are drawn according to the conventions described in paragraph 2-2c above.

b. Figures 3-1 to 3-12 present as boxplots the selected MOE for the STOCEM simulations of the 140-day NEA campaign of SRA-05. In Figure 3-12, negative values indicate a net gain of terrain by Blue.

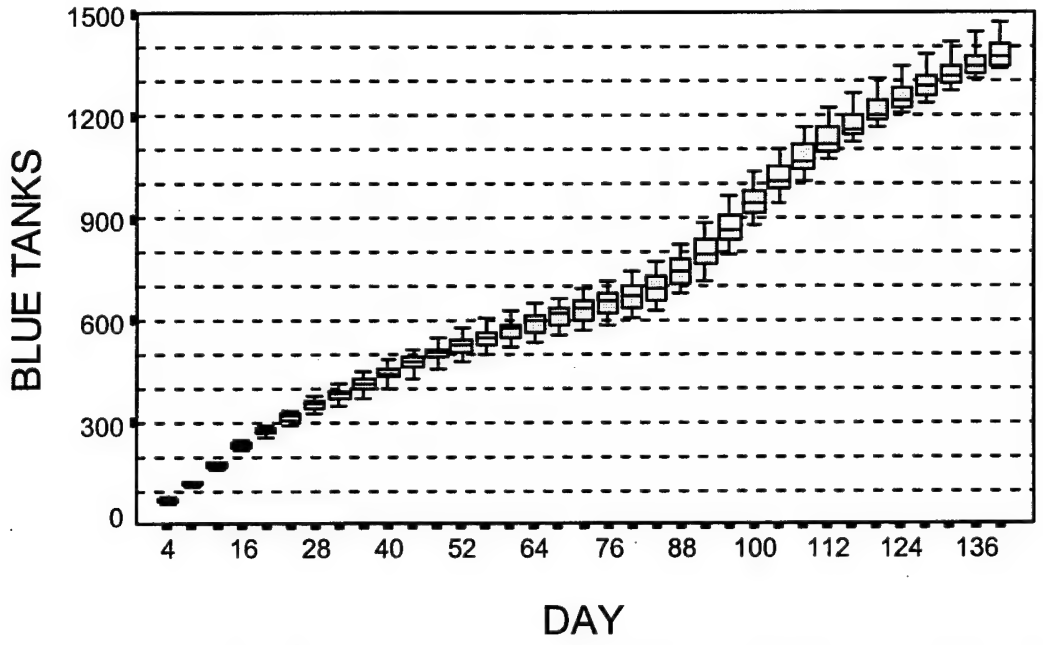

Figure 3-1. Cumulative Permanent Losses of Blue Tanks, STOCEM SRA-05 NEA

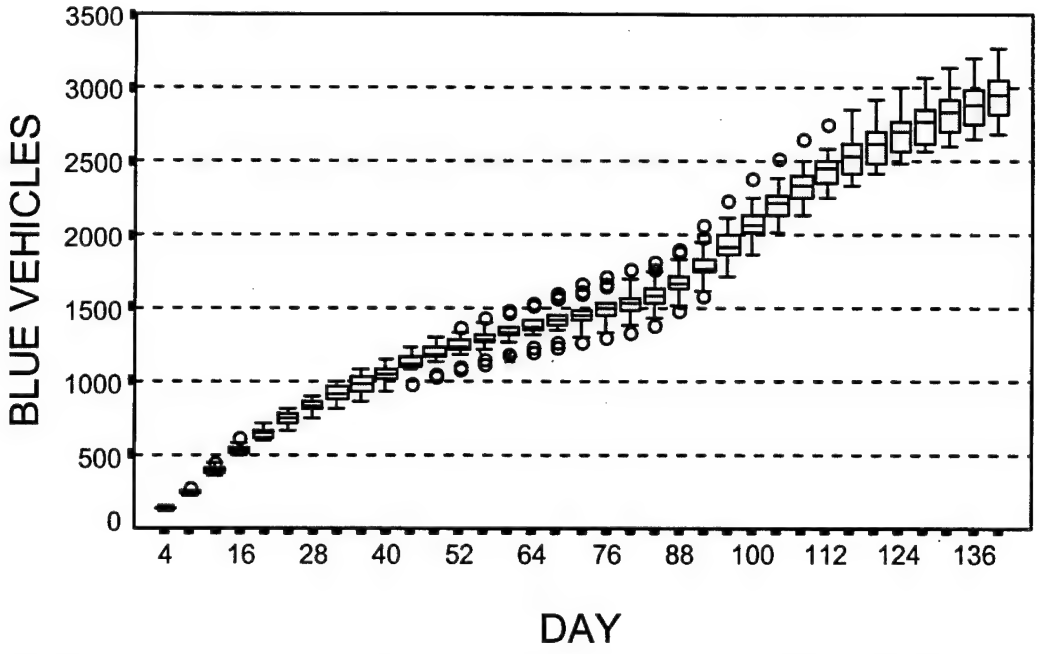

Figure 3-2. Cumulative Permanent Losses of Blue Light Armor, STOCEM SRA-05 NEA

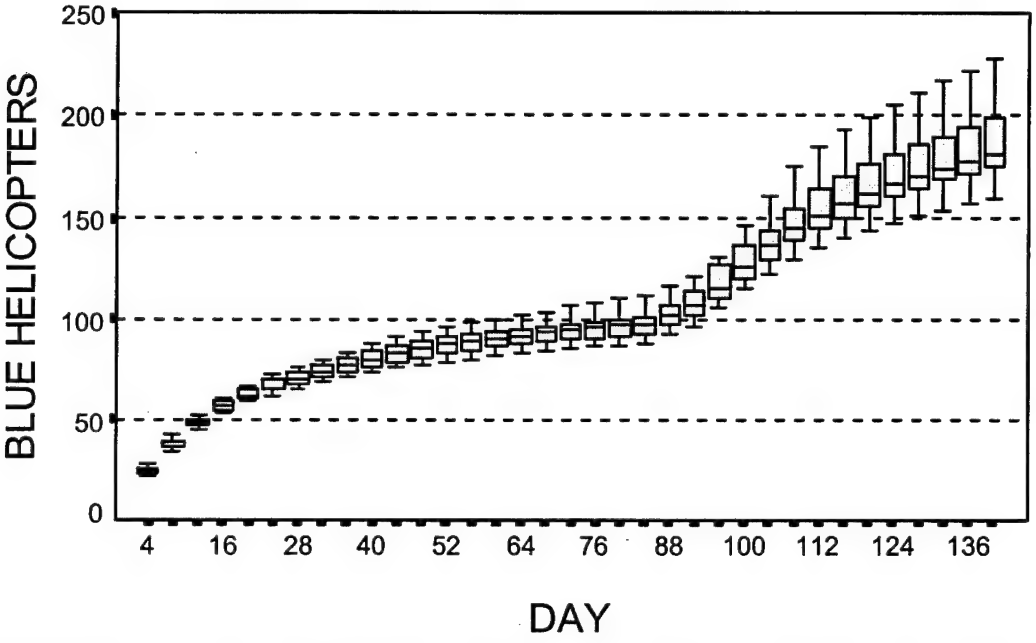

Figure 3-3. Cumulative Permanent Losses of Blue Helicopters, STOCEM SRA-05 NEA

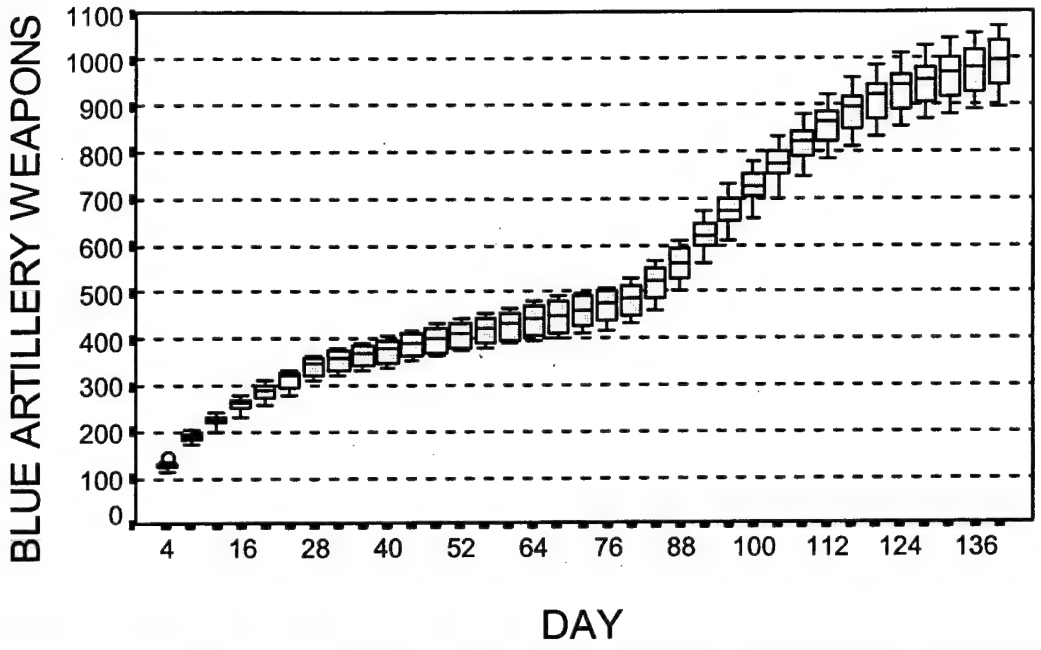

Figure 3-4. Cumulative Permanent Losses of Blue Artillery, STOCEM SRA-05 NEA

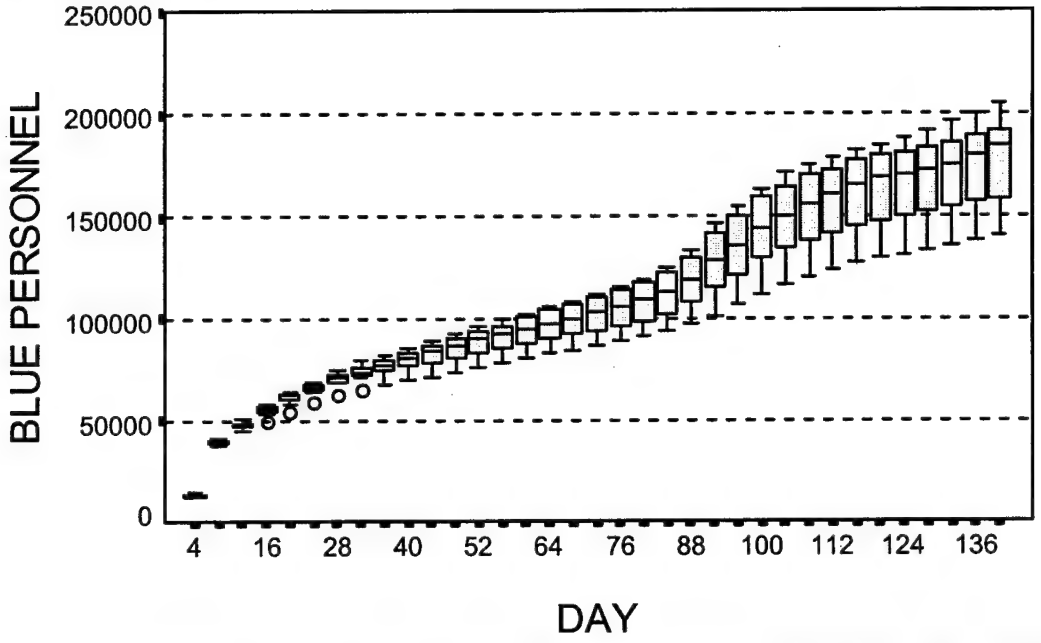

Figure 3-5. Cumulative Permanent Losses of Blue Personnel, STOCEM SRA-05 NEA

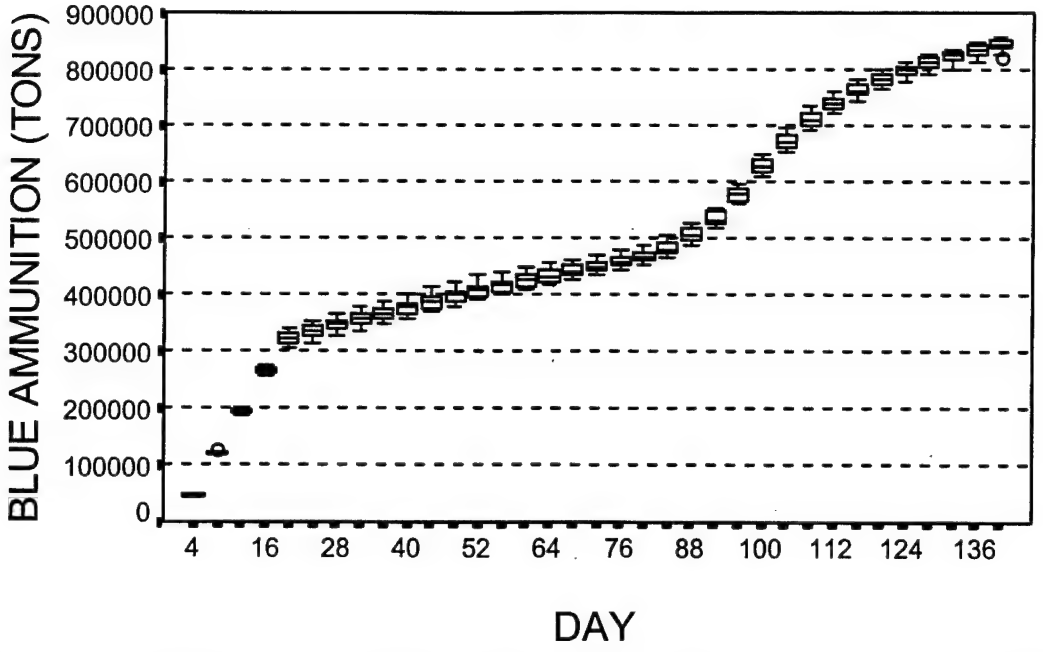

Figure 3-6. Cumulative Consumption of Blue Ammunition, STOCEM SRA-05 NEA

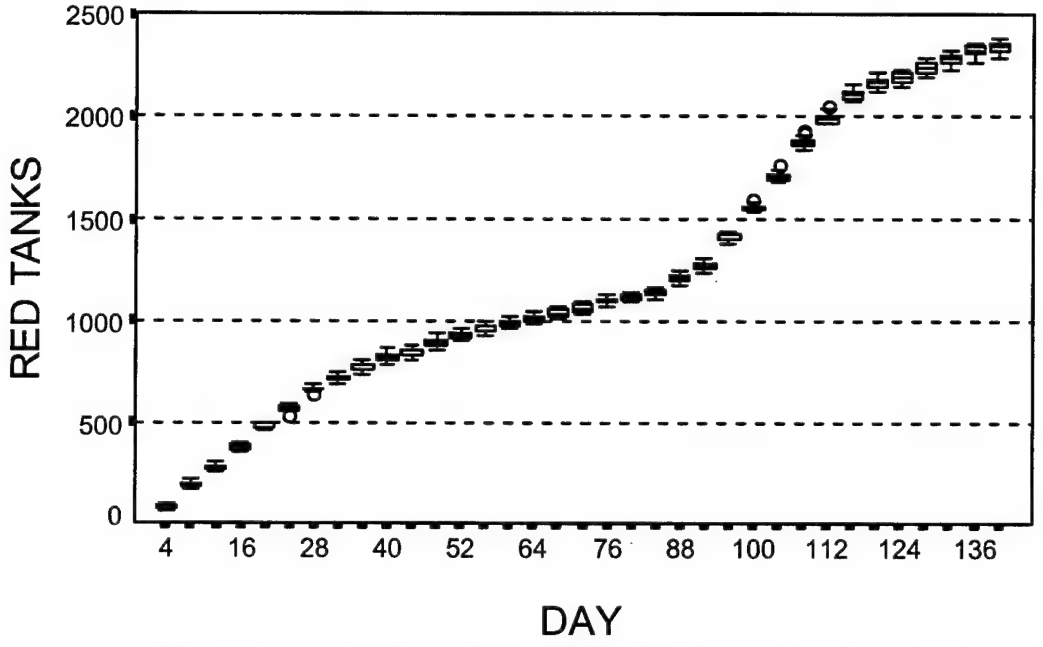

Figure 3-7. Cumulative Permanent Losses of Red Tanks, STOCEM SRA-05 NEA

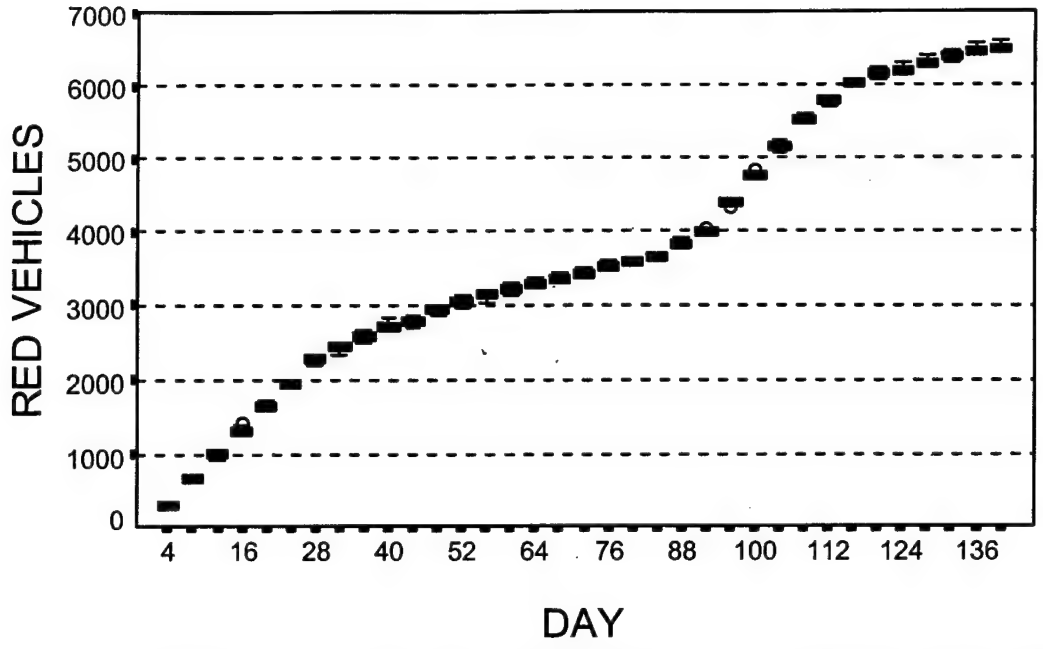

Figure 3-8. Cumulative Permanent Losses of Red Light Armor, STOCEM SRA-05 NEA

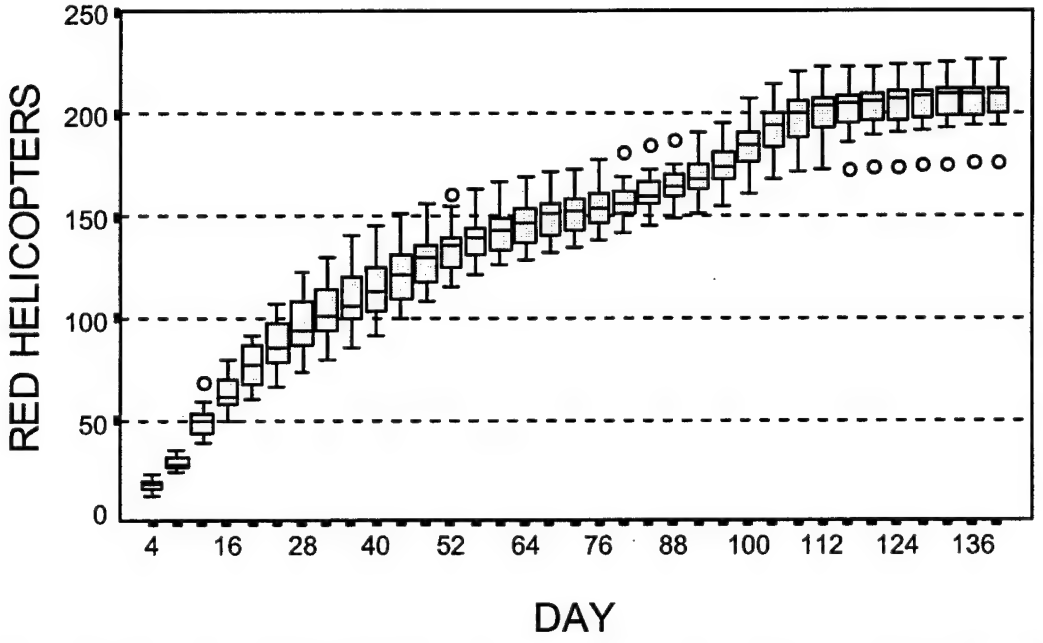

Figure 3-9. Cumulative Permanent Losses of Red Combat Helicopters, STOCEM SRA-05 NEA

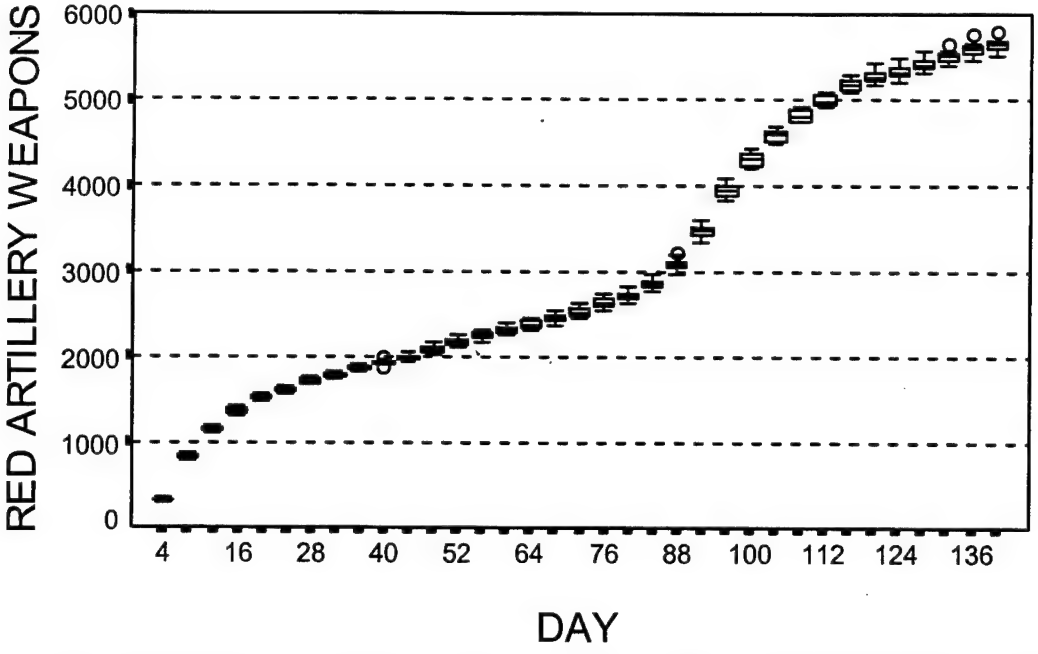

Figure 3-10. Cumulative Permanent Losses of Red Artillery, STOCEM SRA-05 NEA

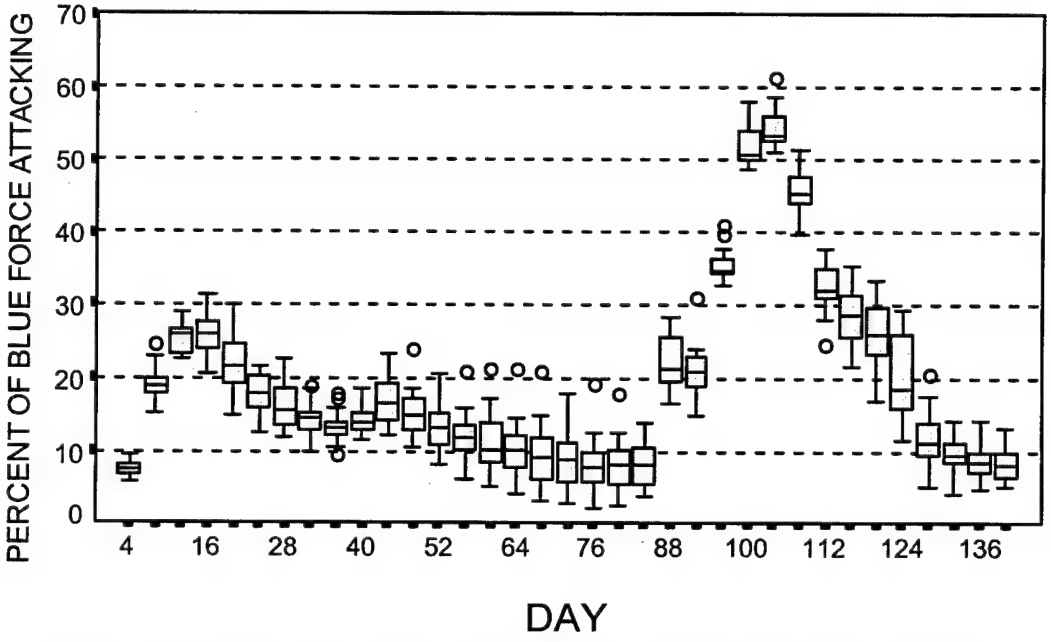

Figure 3-11. Frequency (%) of Blue Attacks, STOCEM SRA-05 NEA

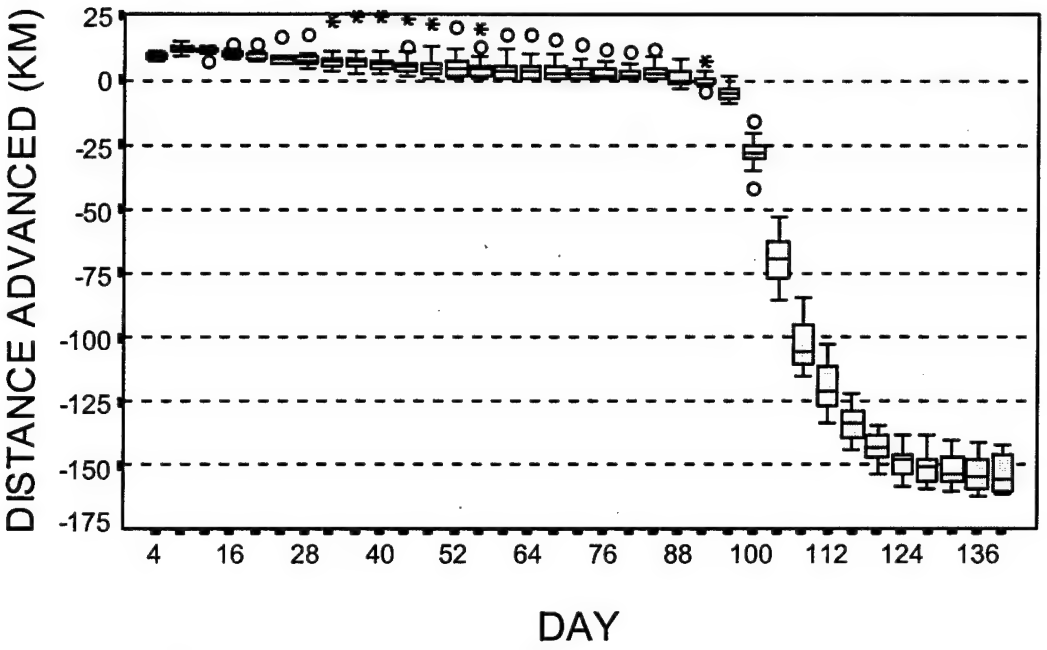

Figure 3-12. Cumulative Average Red Advance Per Sector, STOCEM SRA-05 NEA

c. It is evident from the above figures that the variability among STOCEM replications is small for ammunition consumption and losses of Red tanks, light armor, and artillery. Variation among STOCEM replications is large for losses of Red helicopters and Blue personnel and for posture frequencies.

3-3. COMPARISON OF STOCEM WITH CEM

a. Figures 3-13 to 3-24 show STOCEM base results compared with CEM for selected MOE. Simulation results are reported at 4-day intervals. In each chart, the solid lines show the upper and lower limits of the STOCEM confidence intervals, and the lightly shaded bar shows the deterministic CEM outcome. The confidence intervals displayed in these figures are defined as in paragraph 2-2d above:

$$\text{Confidence limits} = \bar{X} \pm 2.947\, s / \sqrt{4}$$

where $\bar{X}$ is the sample mean and s is the sample standard deviation:

$$s^2 = \sum_i (X_i - \bar{X})^2 / 15.$$

If the distribution of outcomes from the replications of STOCEM satisfies the normality conditions of the Student/Fisher t-statistic, then these displays depict confidence intervals of 99 percent about the mean of the distributions. However, the normality of the population of STOCEM outcomes for each outcome measure for each 4-day period has not been established.

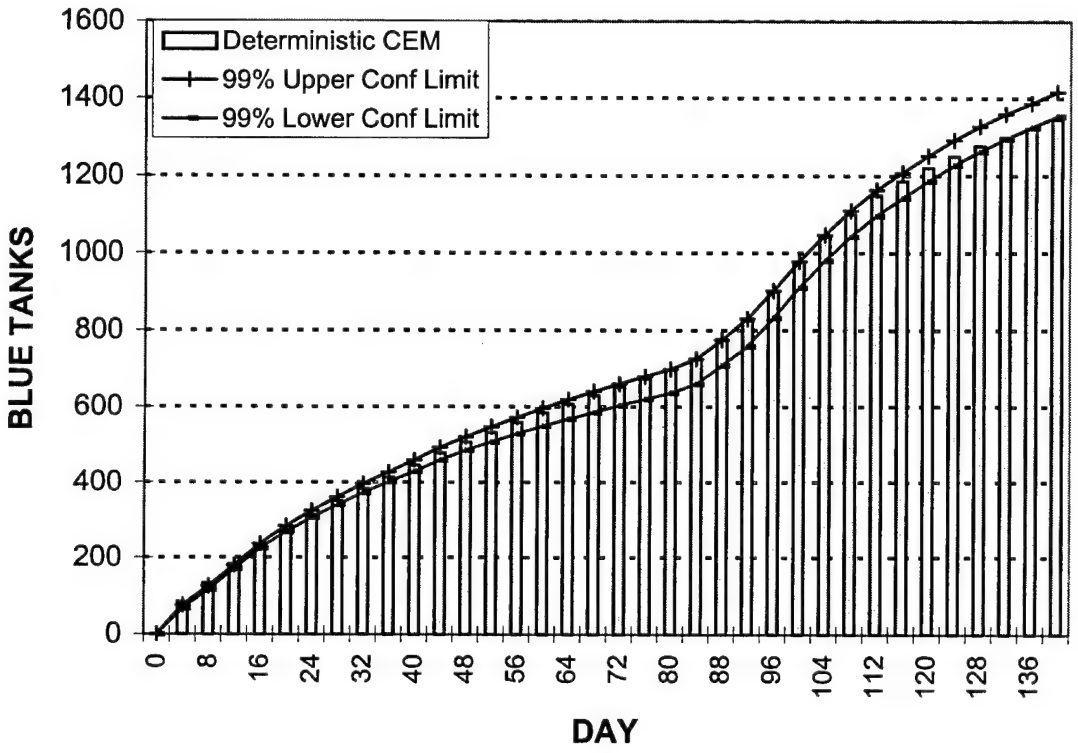

Figure 3-13. Cumulative Permanent Losses of Blue Tanks, SRA-05 NEA STOCEM Confidence Intervals

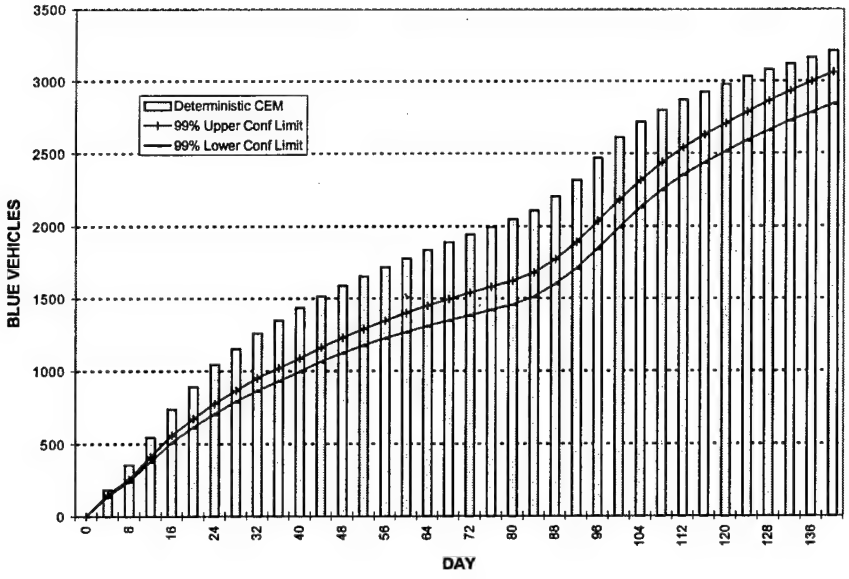

Figure 3-14. Cumulative Permanent Losses of Blue Light Armor, SRA-05 NEA STOCEM Confidence Intervals

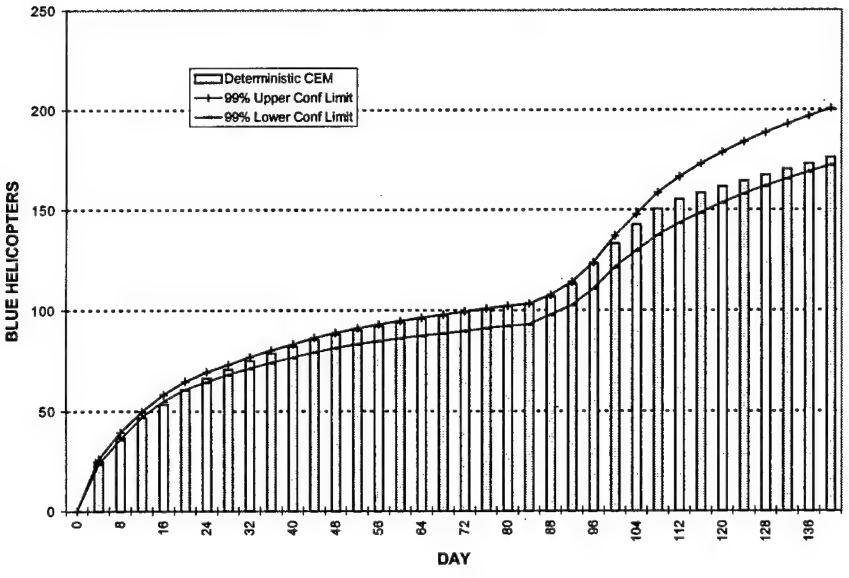

Figure 3-15. Cumulative Permanent Losses of Blue Combat Helicopters, SRA-05 NEA STOCEM Confidence Intervals

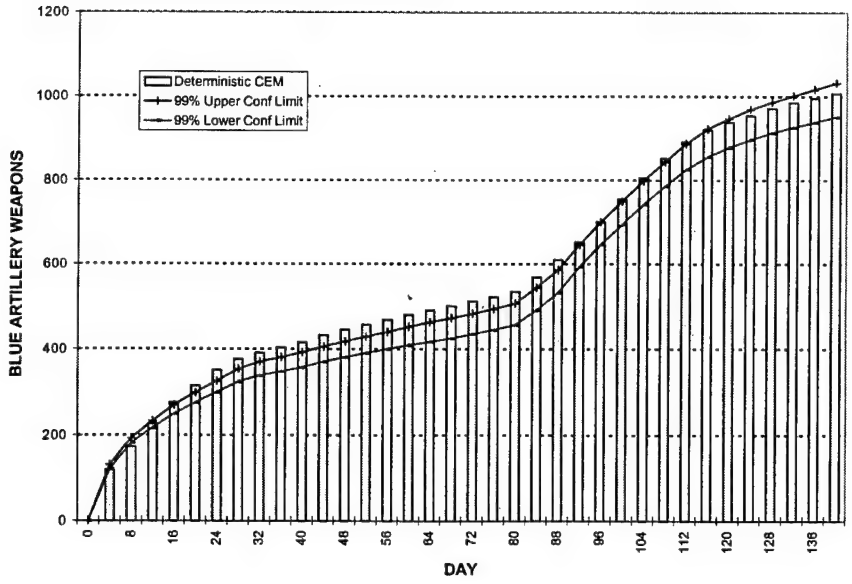

Figure 3-16. Cumulative Permanent Losses of Blue Artillery, SRA-05 NEA STOCEM Confidence Intervals

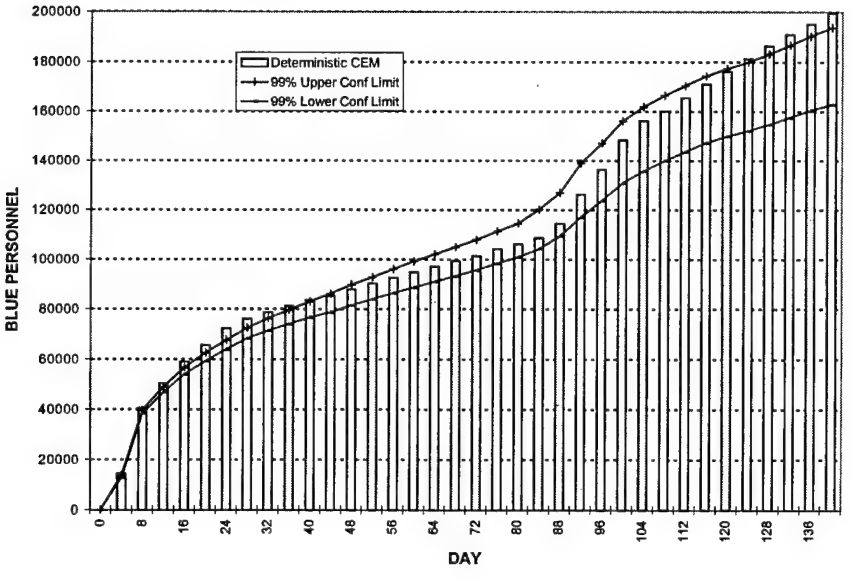

Figure 3-17. Cumulative Permanent Losses of Blue Personnel, SRA-05 NEA STOCEM Confidence Intervals

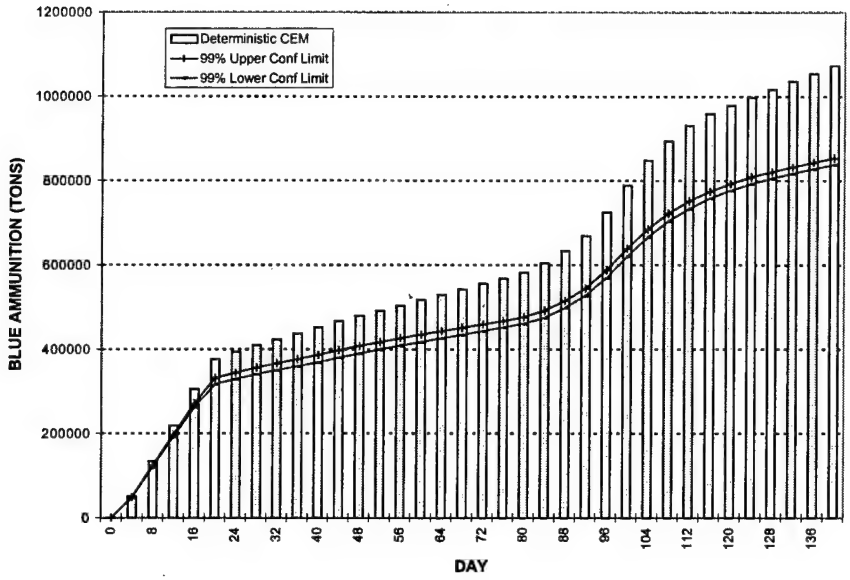

Figure 3-18. Cumulative Consumption of Blue Ammunition, SRA-05 NEA STOCEM Confidence Intervals

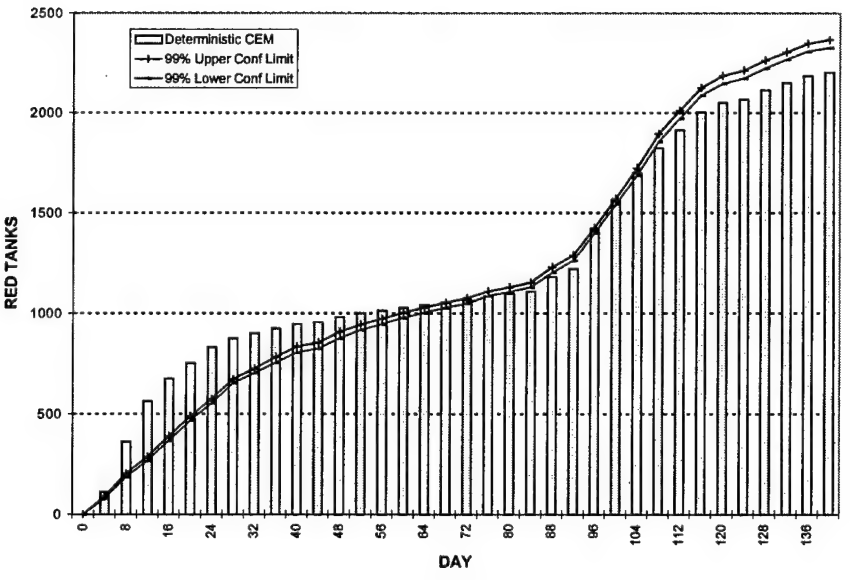

Figure 3-19. Cumulative Permanent Losses of Red Tanks, SRA-05 NEA STOCEM Confidence Intervals

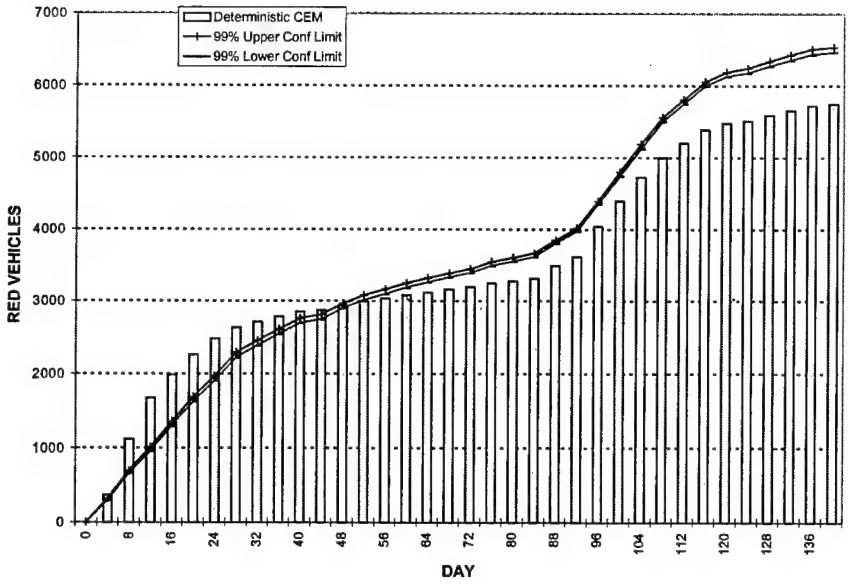

Figure 3-20. Cumulative Permanent Losses of Red Light Armor, SRA-05 NEA STOCEM Confidence Intervals

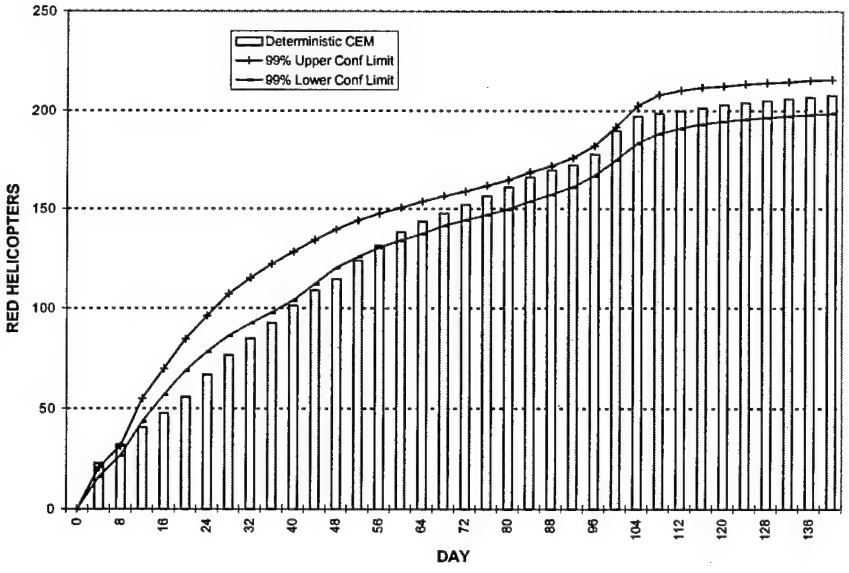

Figure 3-21. Cumulative Permanent Losses of Red Combat Helicopters, SRA-05 NEA STOCEM Confidence Intervals

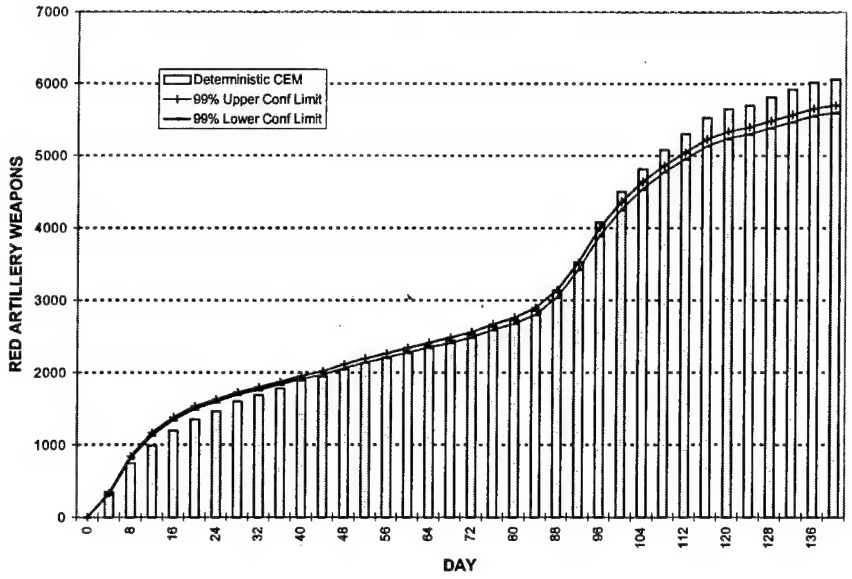

Figure 3-22. Cumulative Permanent Losses of Red Artillery, SRA-05 NEA STOCEM Confidence Intervals

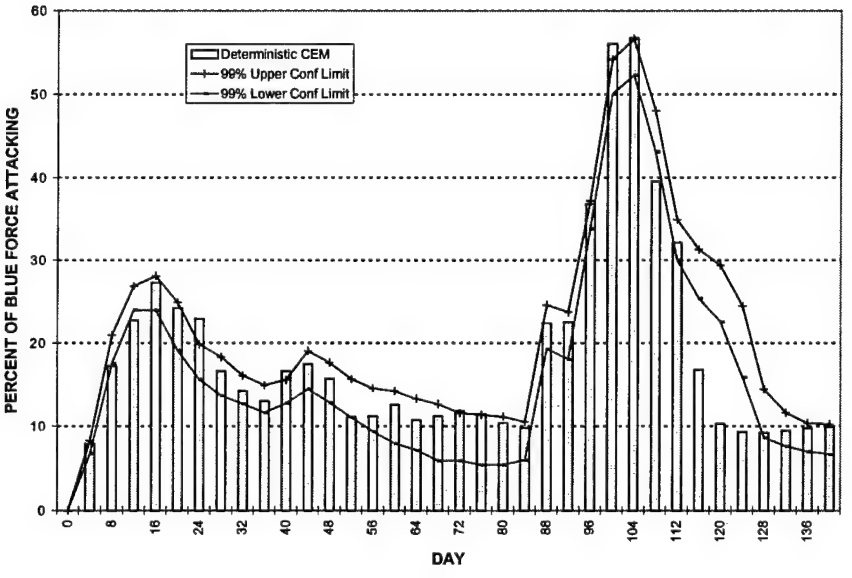

Figure 3-23. Frequency (%) of Blue Attacks, SRA-05 NEA STOCEM Confidence Intervals

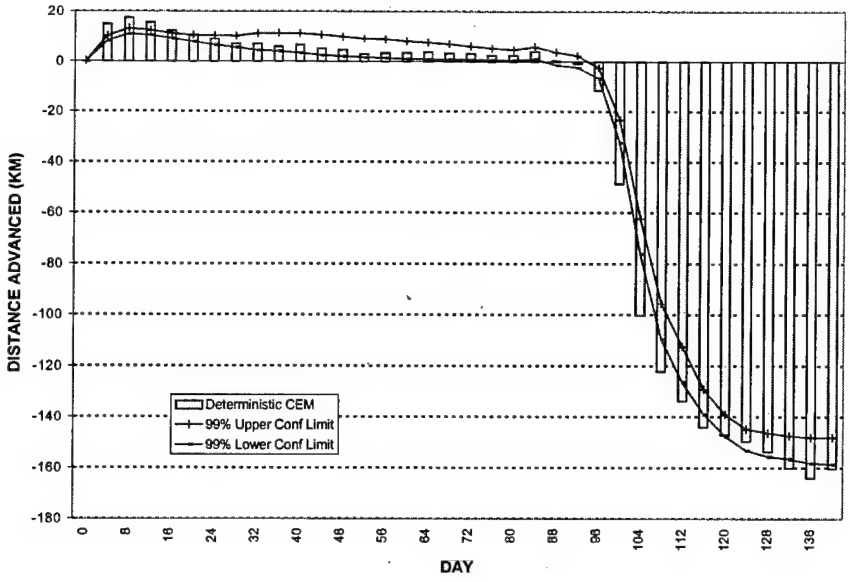

Figure 3-24. Cumulative Average Red Advance Per Sector, SRA-05 NEA STOCEM Confidence Intervals

b. In Figure 3-24, a negative value indicates net gain of terrain by Blue forces. Figures 3-13 to 3-24 show many instances of MOE for which STOCEM results are significantly different from CEM. That is, CEM results lie outside the 99 percent confidence limits of STOCEM for many of the simulated 4-day time periods for the selected MOE. Figures 3-14, 3-18, 3-19, and 3-20 appear to indicate some systemic differences between CEM and STOCEM.

3-4. FEBA LOCATIONS

a. Figure 3-25 displays over a map background the FEBA locations at D+8 of the deterministic CEM (dashed line) and the maximum and minimum (white lines) of the 16 replications of the STOCEM base case. D+8 is the maximum Red advance for CEM and for most of the STOCEM replications, as Figure 3-24 above indicates. Neither the maximum nor minimum FEBA represents an individual replication of STOCEM. Rather, the maximum FEBA shows the maximum north Korean advance at D+8, *by sector*, of the 16 STOCEM replications; so it is a composite of the STOCEM replications. That is, the maximum advance in a western sector might occur in a different STOCEM replication from the maximum advance in an eastern sector of the campaign.

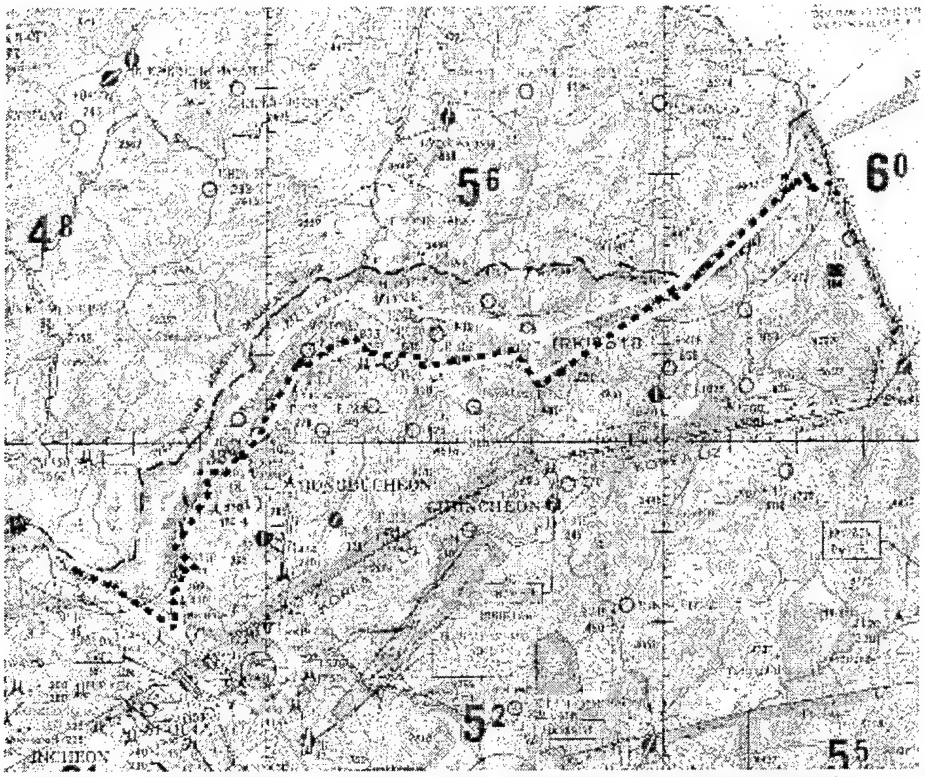

Figure 3-25. D+8 FEBA Locations, SRA-05 NEA STOCEM Maximum and Minimum and CEM

b. Figure 3-25 shows that the results of deterministic CEM are close to the maximum of the STOCEM replications; and the CEM D+8 FEBA is generally between the STOCEM maximum and minimum.

CHAPTER 4

STOCEM BASE CASE, SOUTHWEST ASIA

4-1. SIMULATION CHARACTERISTICS

a. The CEM simulation of SRA-05 southwest Asia was executed in four sequential phases: Days 1-40, Days 41-124, Days 125-140, and Days 141-180. These separate CEM simulations were integrated by CAA's BASECEM programs. Consequently, for the STOCEM simulations reported here, the BASECEM programs were installed on the Cray computer--where STOCEM is executed--and were used to integrate the four phases of each replication of STOCEM.

b. For each phase of the SRA-05 SWA campaign, STOCEM was executed with all the available stochastic processes activated, including the random selection from the COSAGE replications for each subsector engagement within STOCEM. Each of 16 STOCEM replications was run through the 4 phases of the campaign, integrated by the BASECEM programs.

4-2. STOCEM RESULTS DISPLAYED AS BOXPLOTS

a. As in the preceding chapter, boxplots are used to convey the variability among the results of the 16 STOCEM replications. Figures 4-1 to 4-11 contain a boxplot for every 4-day period simulated, through D+180. Each figure provides the results for a selected MOE of the simulated campaign. The boxplot conventions are described in paragraph 3-2a above. In Figure 4-11 negative values indicate a net gain of terrain by Blue.

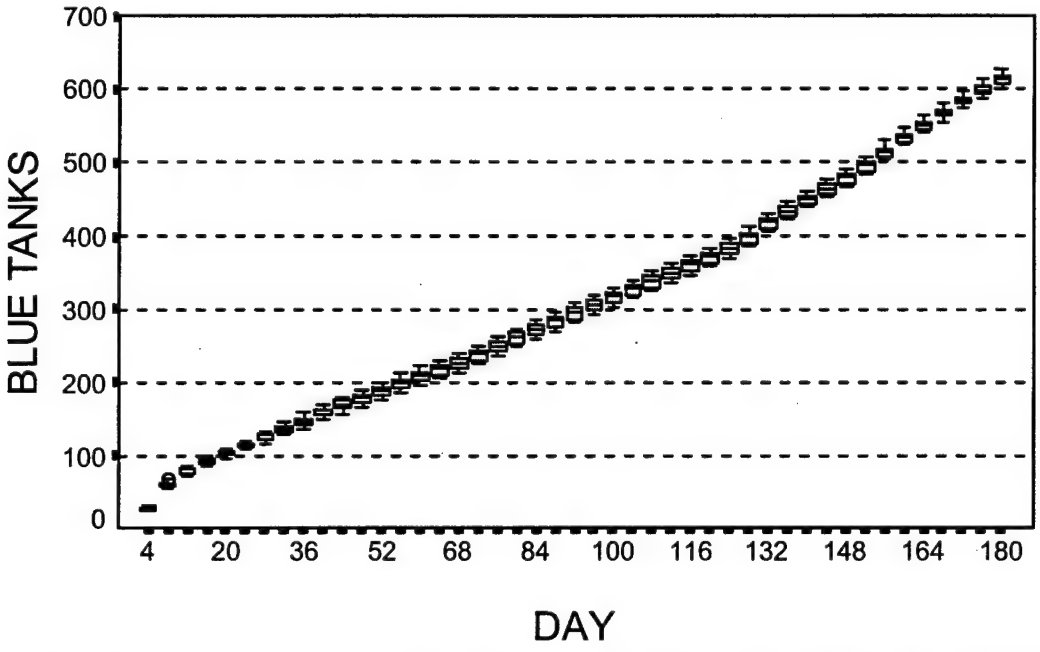

Figure 4-1. Cumulative Permanent Losses of Blue Tanks, STOCEM SRA-05 SWA

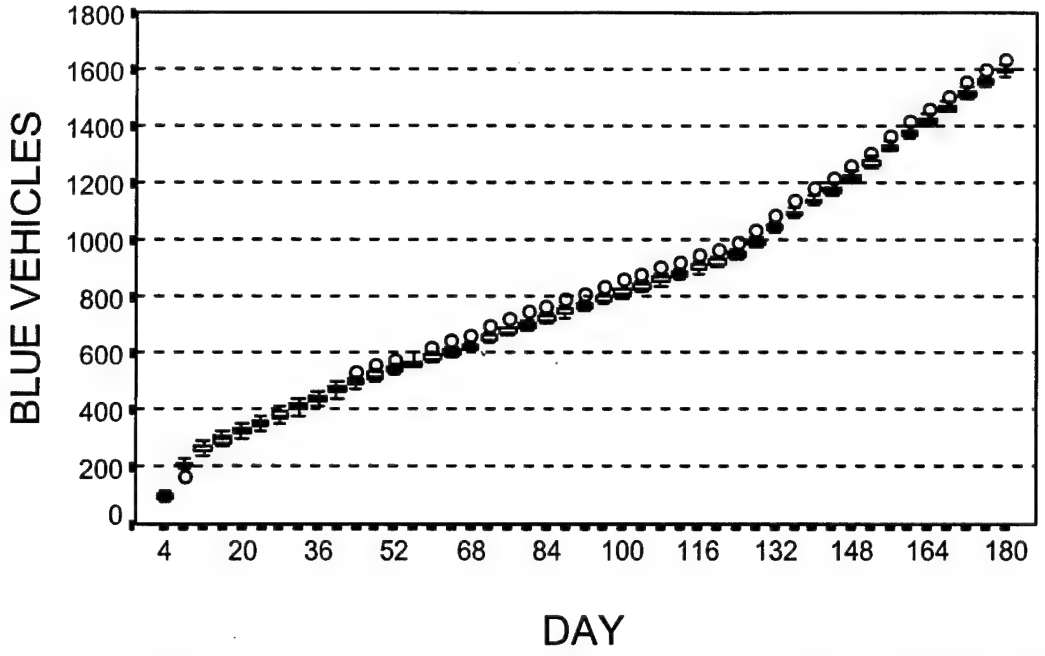

Figure 4-2. Cumulative Permanent Losses of Blue Light Armor, STOCEM SRA-05 SWA

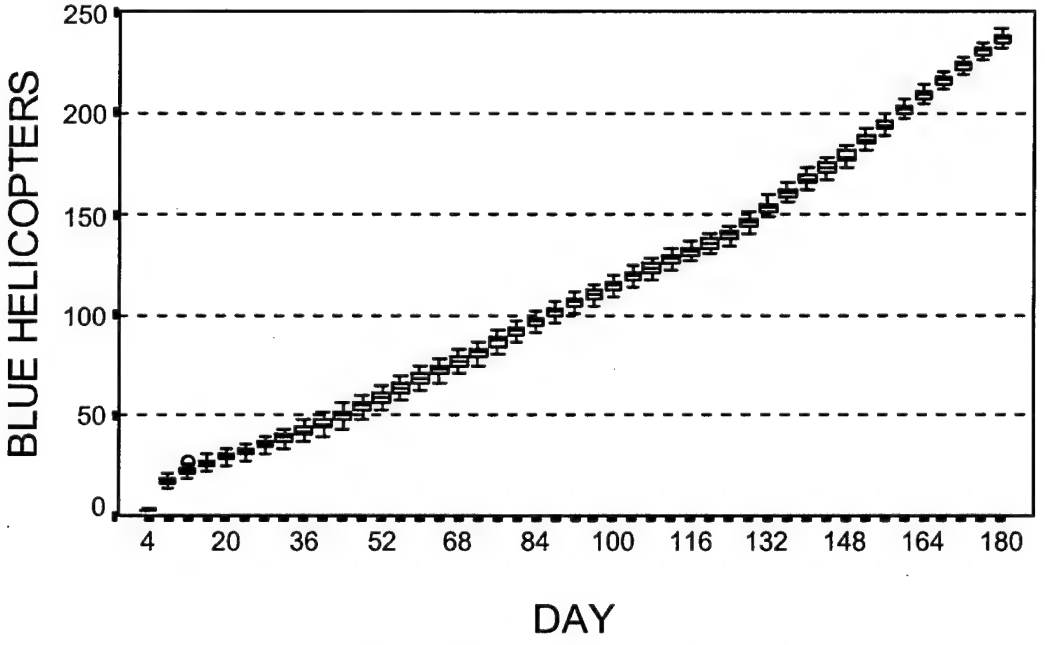

Figure 4-3. Cumulative Permanent Losses of Blue Combat Helicopters, STOCEM SRA-05 SWA

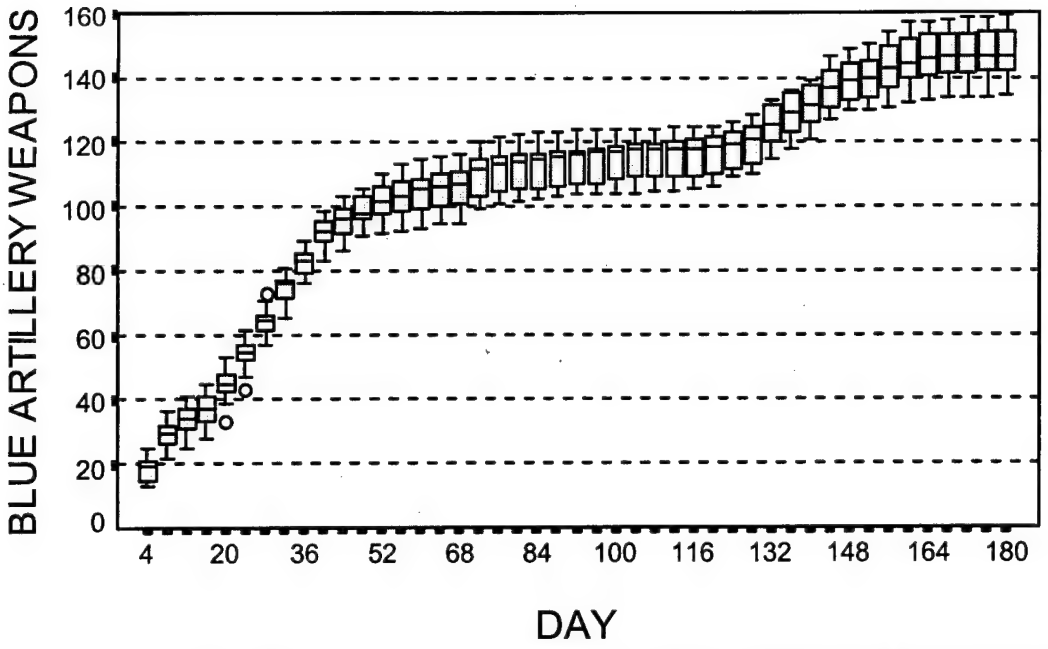

Figure 4-4. Cumulative Permanent Losses of Blue Artillery, STOCEM SRA-05 SWA

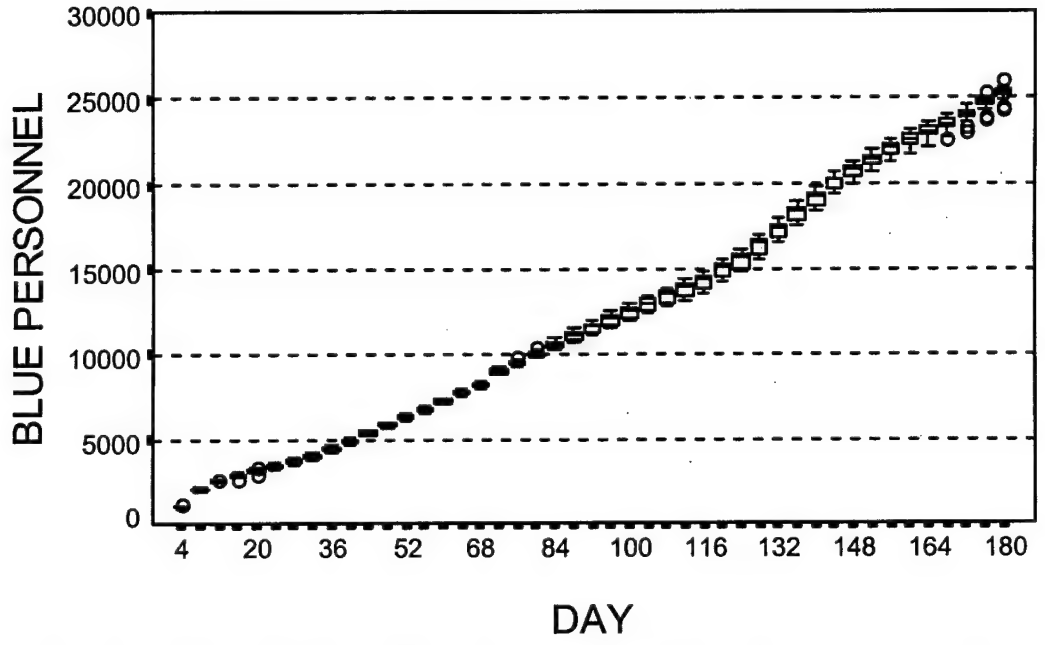

Figure 4-5. Cumulative Permanent Losses of Blue Personnel, STOCEM SRA-05 SWA

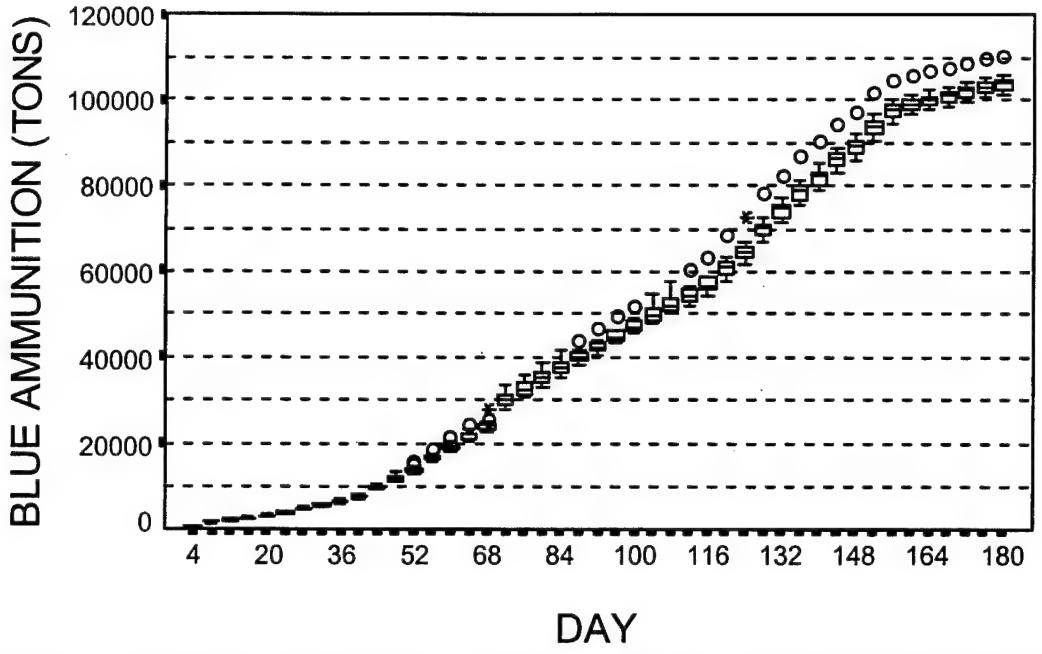

Figure 4-6. Cumulative Consumption of Blue Ammunition, STOCEM SRA-05 SWA

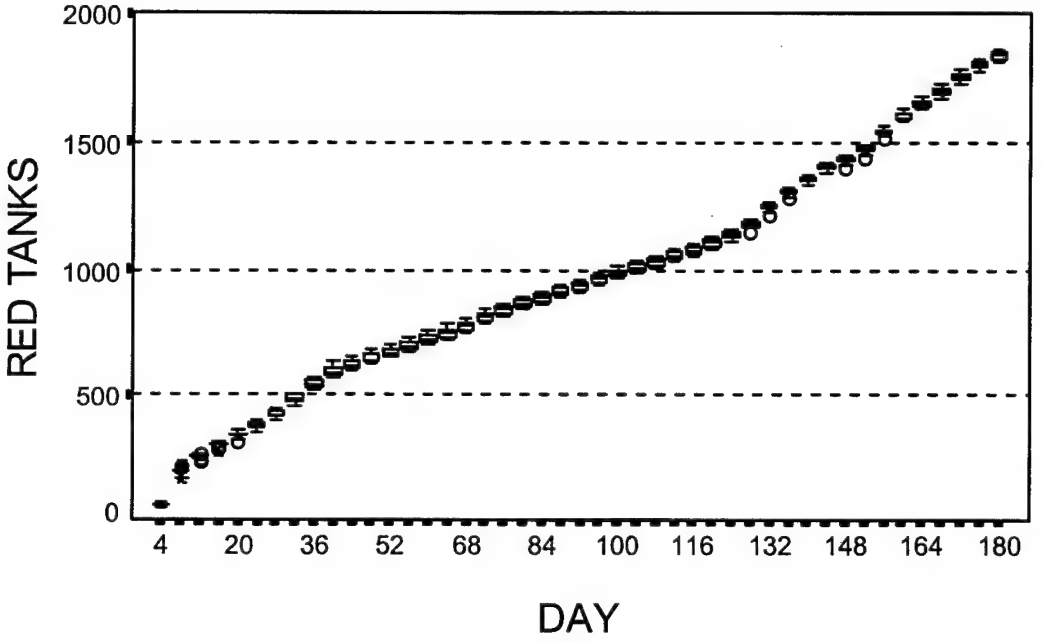

Figure 4-7. Cumulative Permanent Losses of Red Tanks, STOCEM SRA-05 SWA

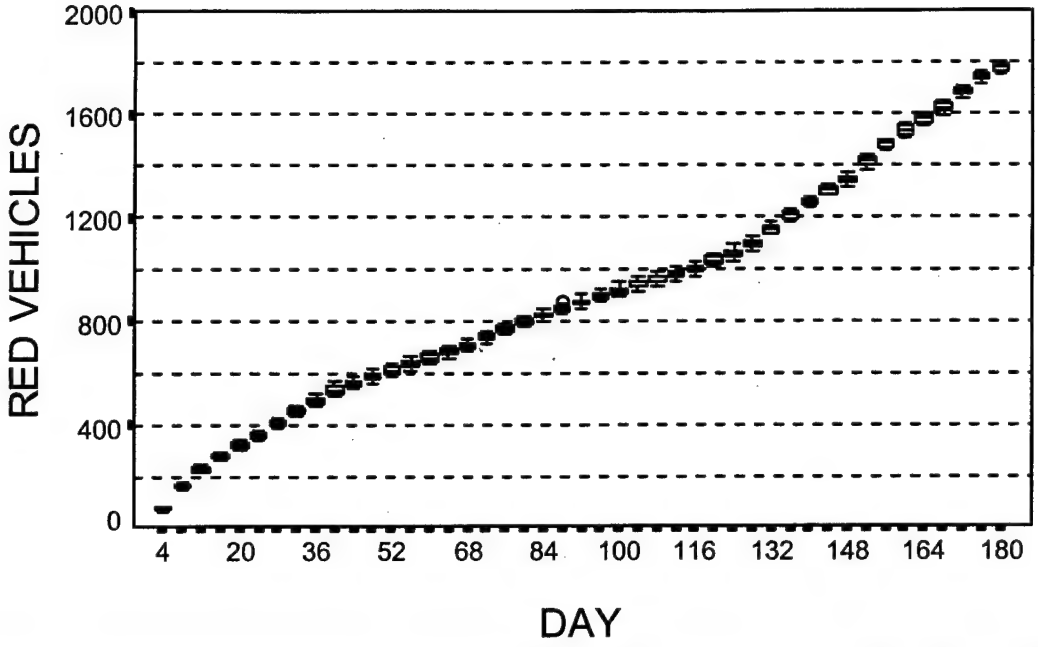

Figure 4-8. Cumulative Permanent Losses of Red Light Armor, STOCEM SRA-05 SWA

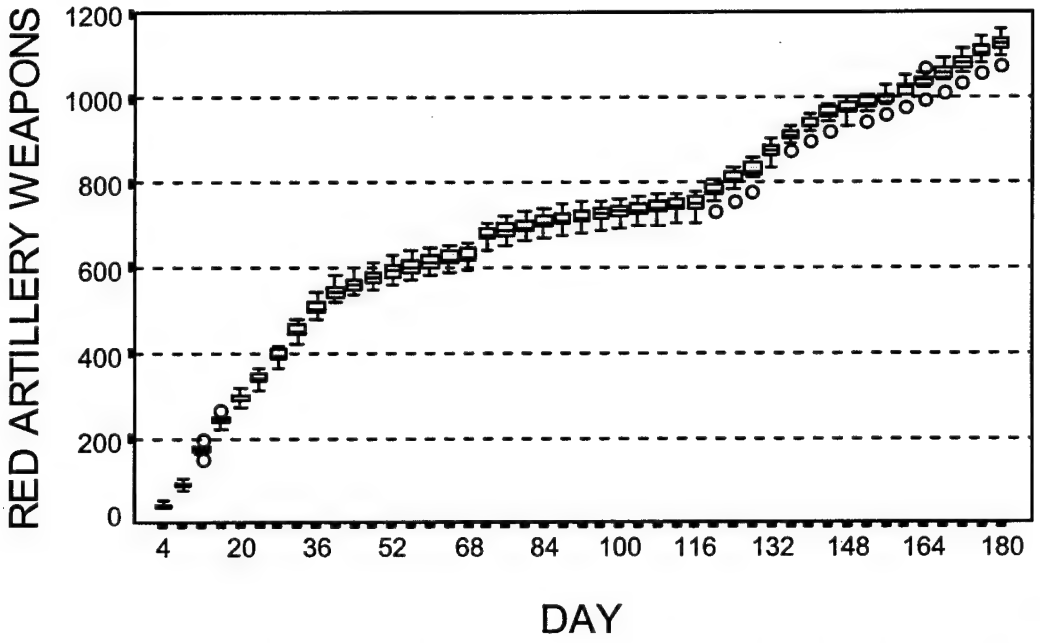

Figure 4-9. Cumulative Permanent Losses of Red Artillery, STOCEM SRA-05 SWA

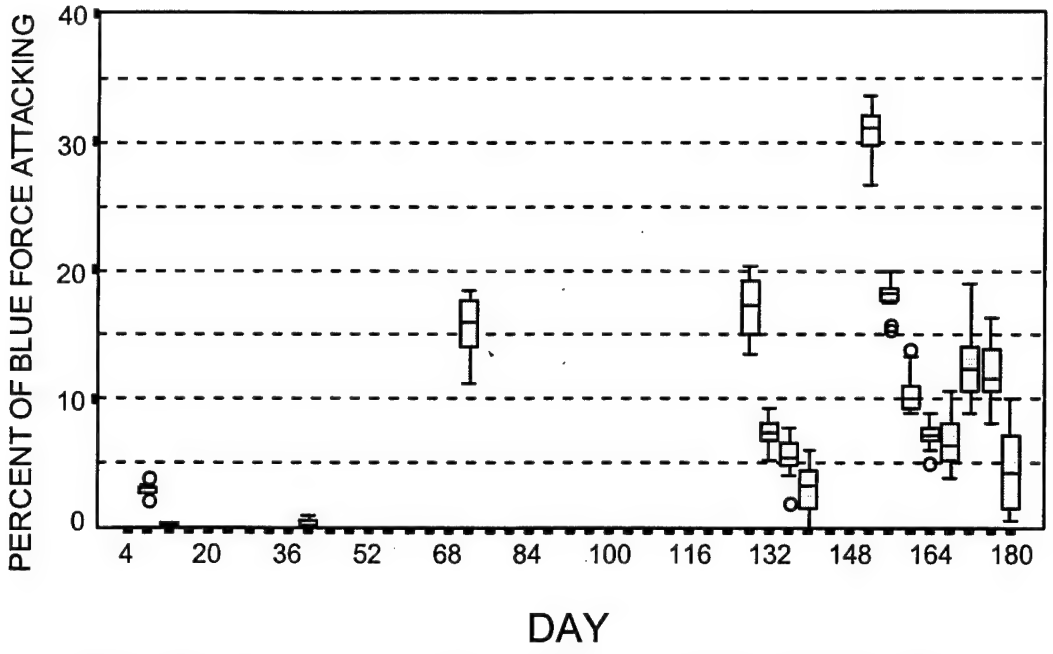

Figure 4-10. Frequency of Blue Attacks, STOCEM SRA-05 SWA

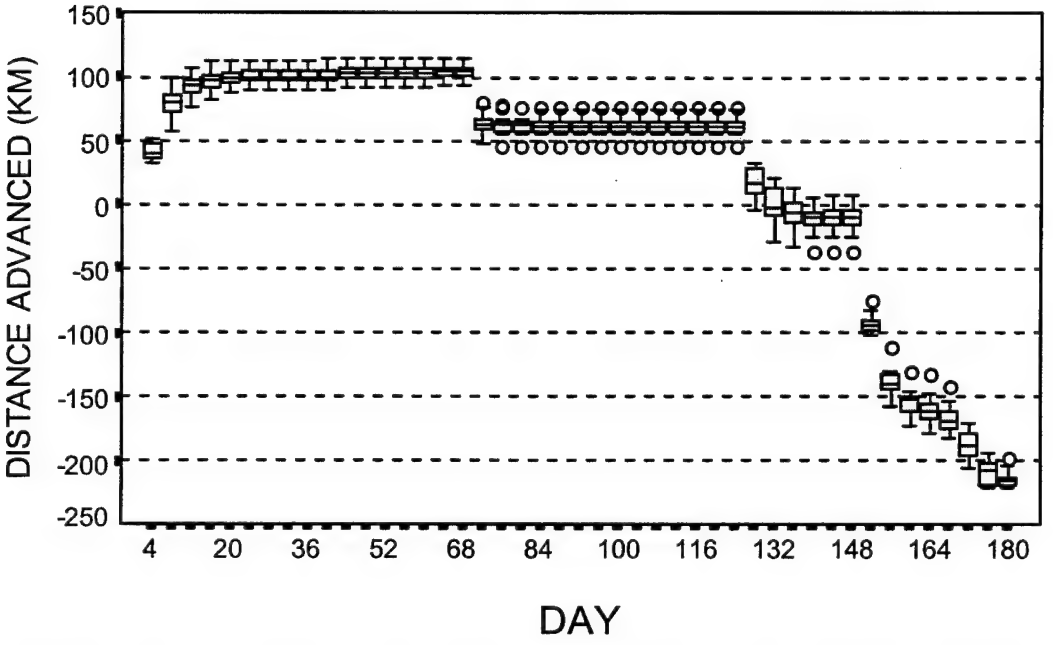

Figure 4-11. Cumulative Average Red Advance Per Sector, STOCEM SRA-05 SWA

b. Figures 4-1 to 4-11 show that the variability among STOCEM replications is small for losses of tanks, light armor, and helicopters. (Losses of Red helicopters are not shown because Red combat helicopter permanent losses were negligible--fewer than 9.0--throughout the SWA campaign.) Variability among STOCEM replications was large for attack frequency, FEBA movement (Figure 4-11), and losses of artillery.

4-3. COMPARISON OF STOCEM WITH CEM

a. Figures 4-12 to 4-22 show the STOCEM results for selected MOE compared with the SRA-05 SWA CEM results. In each figure for every 4-day time period, the bar height shows the deterministic CEM outcome. The lines denote the upper and lower limits of the confidence intervals whose midpoint is the mean of the STOCEM replications. The 99 percent confidence limits about the STOCEM mean are defined as in par. 2-2d above. In Figure 4-22, negative values indicate a net gain of terrain by Blue.

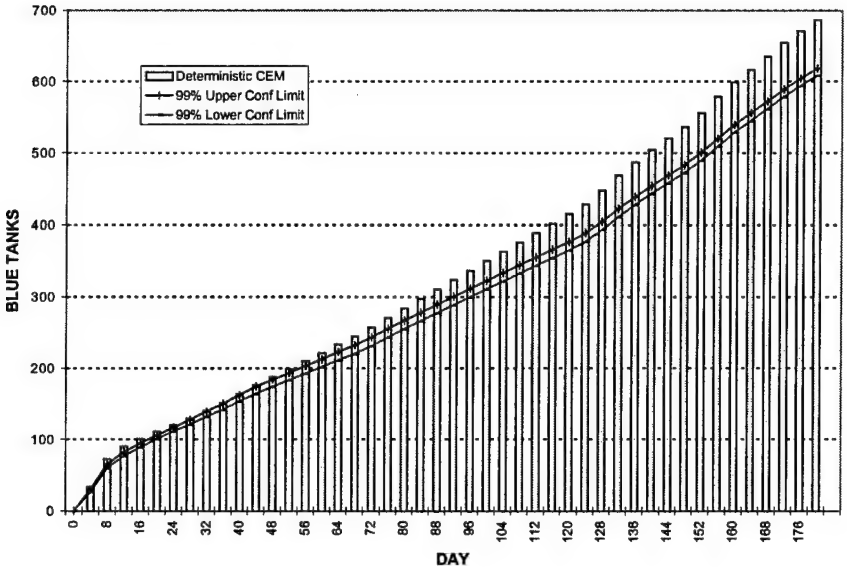

Figure 4-12. Cumulative Permanent Losses of Blue Tanks, SRA-05 SWA STOCEM Confidence Intervals

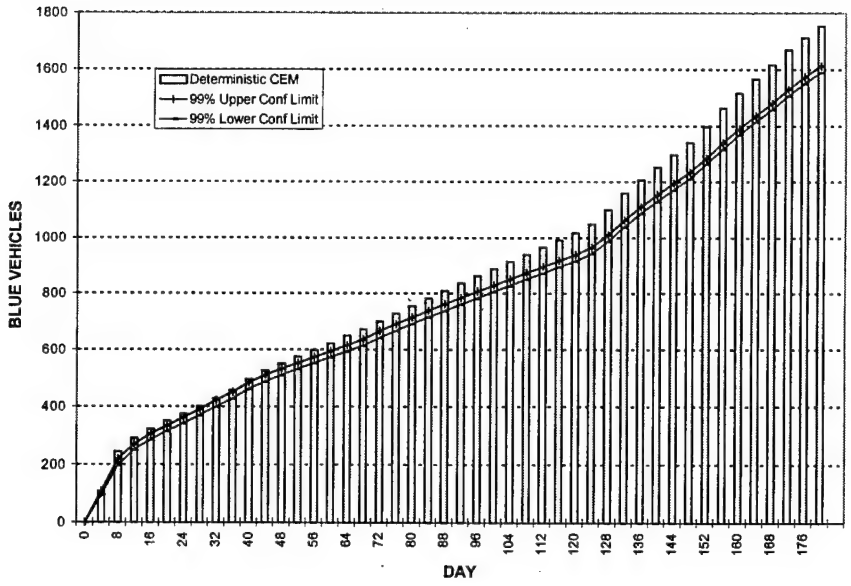

Figure 4-13. Cumulative Permanent Losses of Blue Light Armor, SRA-05 SWA STOCEM Confidence Intervals

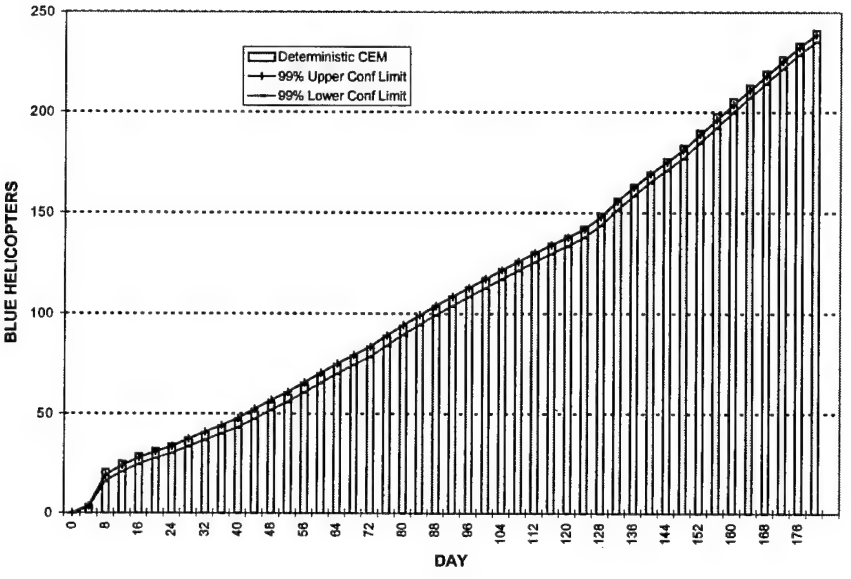

Figure 4-14. Cumulative Permanent Losses of Blue Combat Helicopters, SRA-05 SWA STOCEM Confidence Intervals

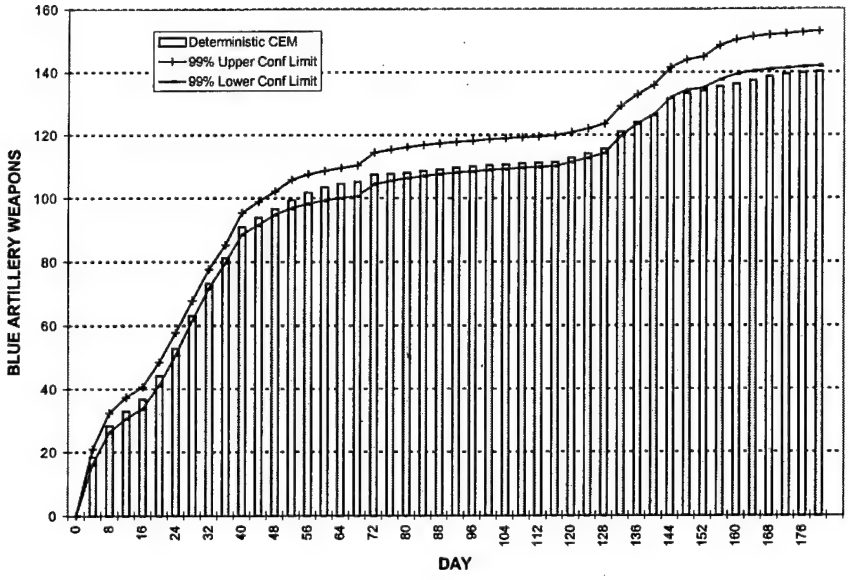

Figure 4-15. Cumulative Permanent Losses of Blue Artillery, SRA-05 SWA STOCEM Confidence Intervals

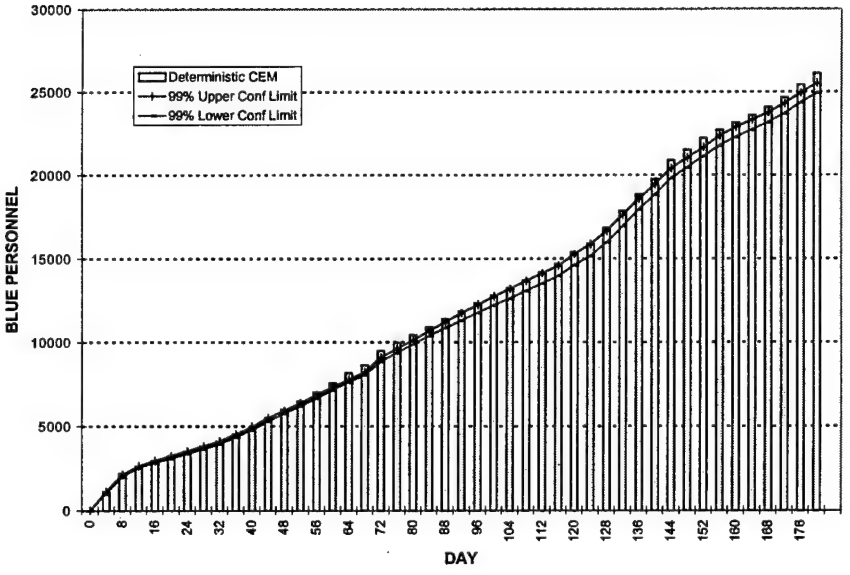

Figure 4-16. Cumulative Permanent Losses of Blue Personnel, SRA-05 SWA STOCEM Confidence Intervals

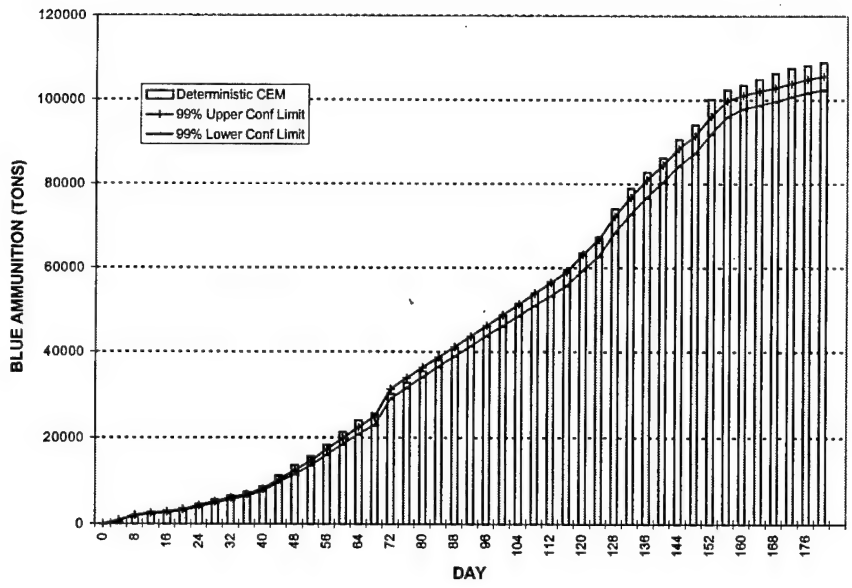

Figure 4-17. Cumulative Consumption of Blue Ammunition, SRA-05 SWA STOCEM Confidence Intervals

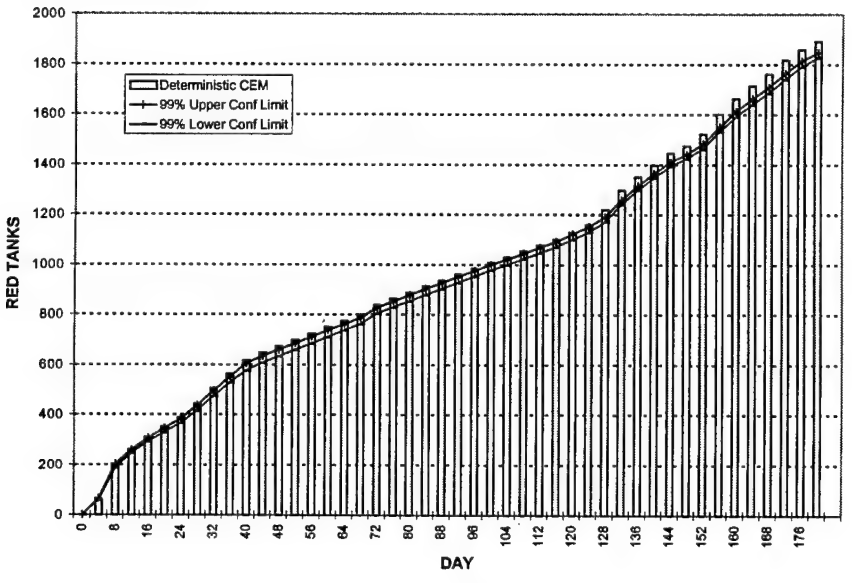

Figure 4-18. Cumulative Permanent Losses of Red Tanks, SRA-05 SWA STOCEM Confidence Intervals

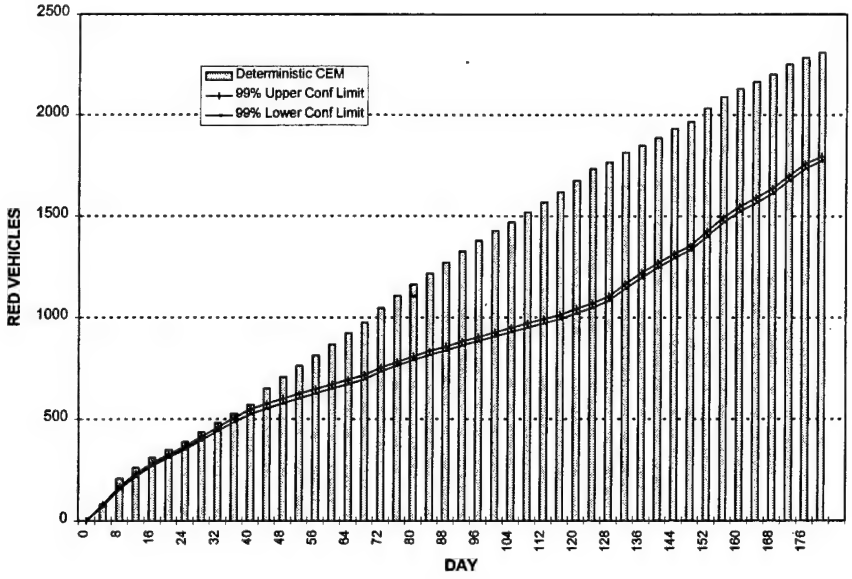

Figure 4-19. Cumulative Permanent Losses of Red Light Armor, SRA-05 SWA STOCEM Confidence Intervals

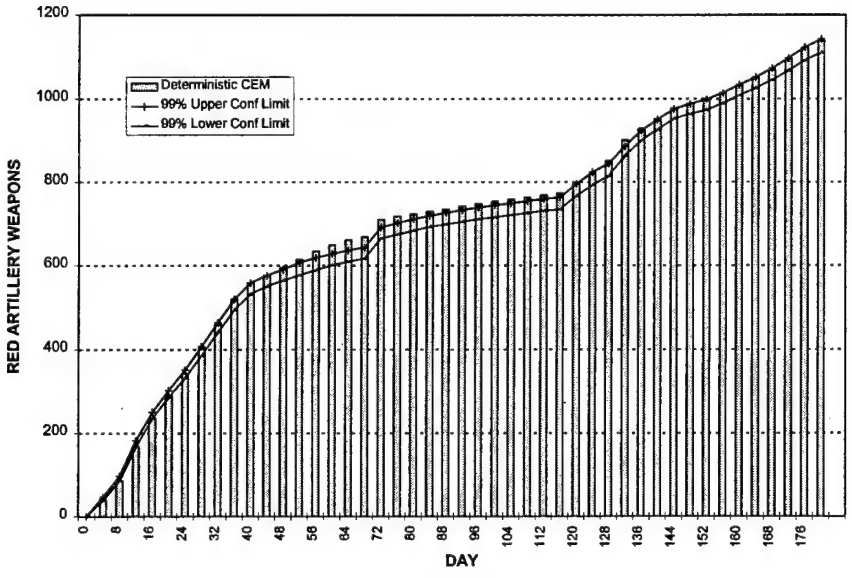

Figure 4-20. Cumulative Permanent Losses of Red Artillery, SRA-05 SWA STOCEM Confidence Intervals

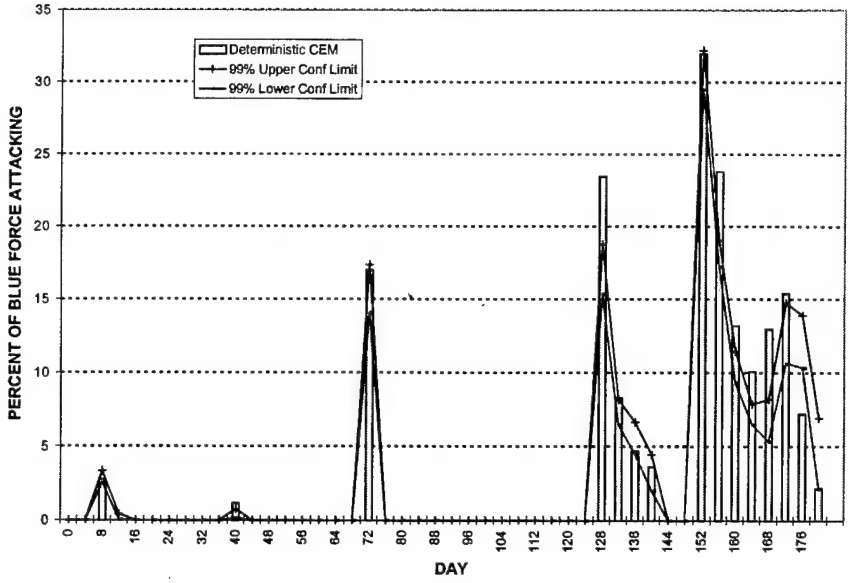

Figure 4-21. Frequency (%) of Blue Attacks, SRA-05 SWA STOCEM Confidence Intervals

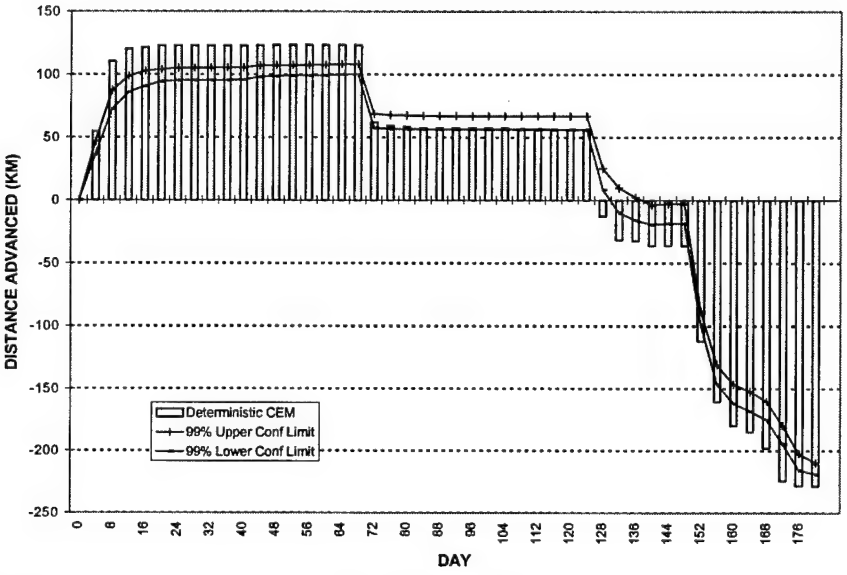

Figure 4-22. Cumulative Red Advance Per Sector, SRA-05 SWA STOCEM Confidence Intervals

b. Figures 4-12 to 4-22 show many time periods for the selected MOE in which the deterministic CEM result is outside the 99 percent confidence limits of STOCEM. In particular, the losses of Red and Blue light armor and of Blue tanks are significantly greater in CEM than in STOCEM for almost all the time periods simulated. Figure 4-19 appears to indicate systemic

differences between CEM and STOCEM. Also, the attacking side advances significantly farther in CEM than in STOCEM.

4-4. FEBA LOCATIONS

a. Figure 4-23 shows the cumulative distance advanced by Blue forces in each CEM/STOCEM minisector at D+40--the end of the first phase of the campaign. Negative values indicate a net gain by Red forces. CEM/STOCEM "minisectors" go in ascending order generally from the west to east boundaries of the theater; that is, the first minisector is farthest to the west. In Figure 4-23 it can be seen that by D+40, on minisectors 101 to 280, Red forces advance farther in CEM than in the "worst case" of the STOCEM replications.

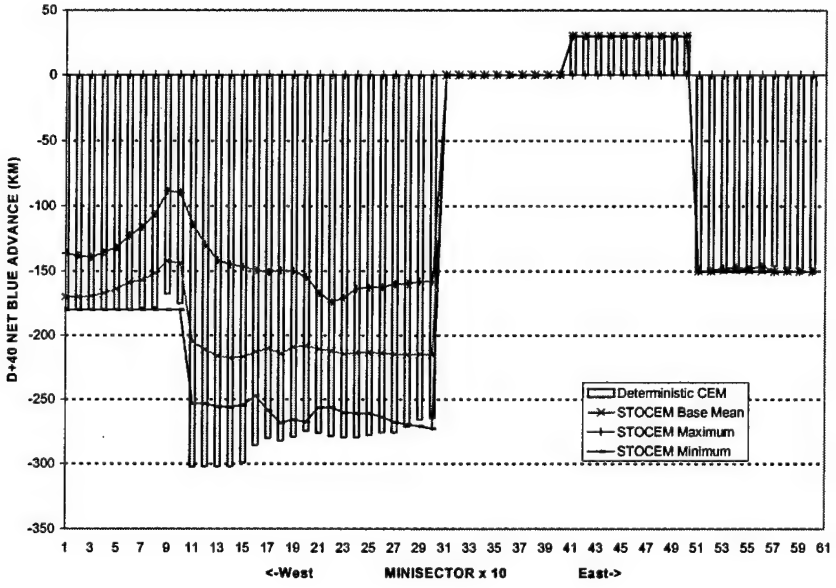

Figure 4-23. D+40 FEBA Location by Sector, SRA-05 SWA STOCEM and CEM

b. Figure 4-24 shows the cumulative distance advanced by Blue forces in each CEM/STOCEM minisector at D+140--the end of the third phase of the campaign. Again, negative values indicate a net gain by Red forces.

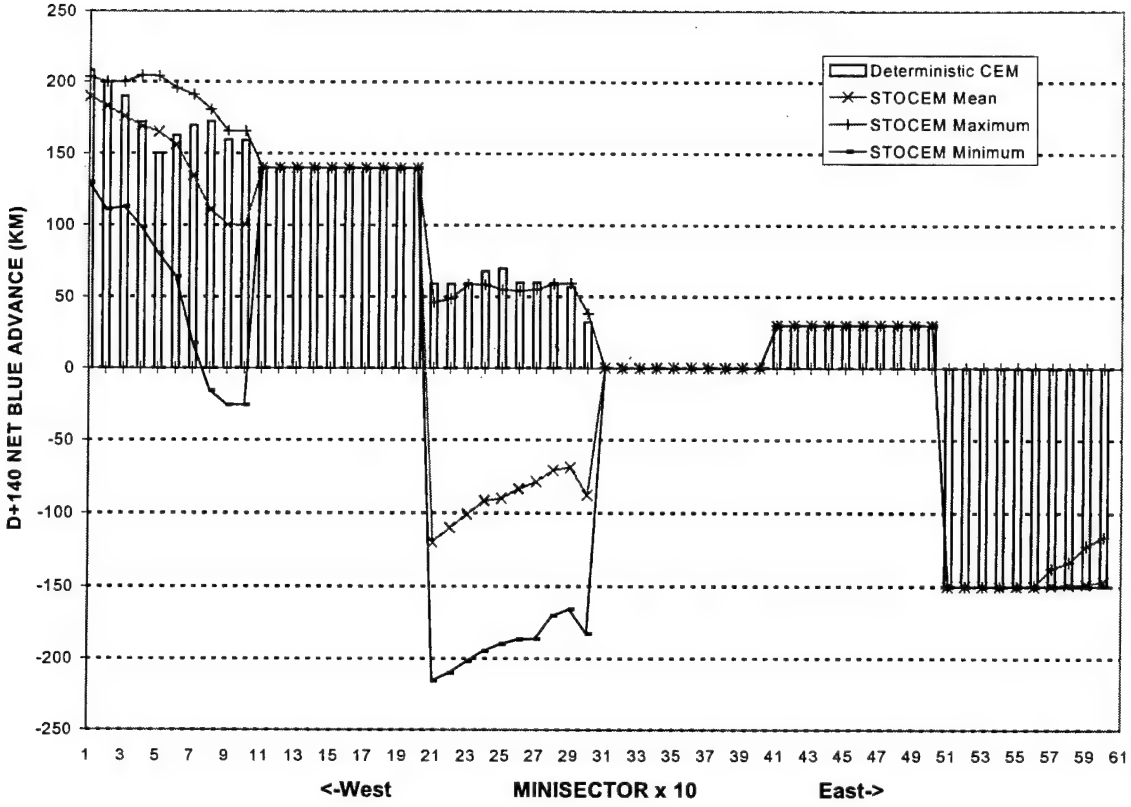

Figure 4-24. D+140 FEBA Location by Sector, SRA-05 SWA STOCEM and CEM

c. Figure 4-24 shows Blue forces advancing slightly farther in CEM than in the "best" of STOCEM simulations, on minisectors 201 to 300; the STOCEM mean value for these minisectors is negative, while the CEM value is positive. Otherwise the CEM results fall within the range of STOCEM results.

CHAPTER 5

A STOCEM VARIATION

5-1. SIMULATION CHARACTERISTICS

a. The SICS research effort (Ref. 7), completed at CAA in July 1997, recommended a partially stochastic way of operating STOCEM:

(1) Calculate rates of advance deterministically, as in CEM. That is, deactivate STOCEM's stochastic estimation of rates of advance.

(2) Use a single replication of COSAGE for each posture throughout a replication of STOCEM. The COSAGE replication for each posture would be selected at random before executing STOCEM. This approach has the beneficial side effect of substantially reducing the computer memory required to operate STOCEM, because only a single replication of COSAGE for each posture must be in memory during a given STOCEM replication.

b. Using this operating mode another set of 16 STOCEM replications was executed for each theater of SRA-05. For the SWA campaign, only the first 40 days (Phase 1) were executed.

5-2. RESULTS OF STOCEM VARIATION, NEA

a. Figures 5-1 to 5-12 show, the results of this STOCEM variation in simulating the SRA-05 NEA campaign, compared with the STOCEM base case and deterministic CEM for the selected MOE. STOCEM results are presented as 99 percent confidence intervals for every 4-day period simulated. The confidence limits are determined as described in paragraph 2-2d above. In each figure the confidence limits for the partially stochastic variation of STOCEM are drawn with dashed lines, the confidence limits for the STOCEM base case are drawn with solid lines, and deterministic CEM results are indicated by the height of the vertical bars.

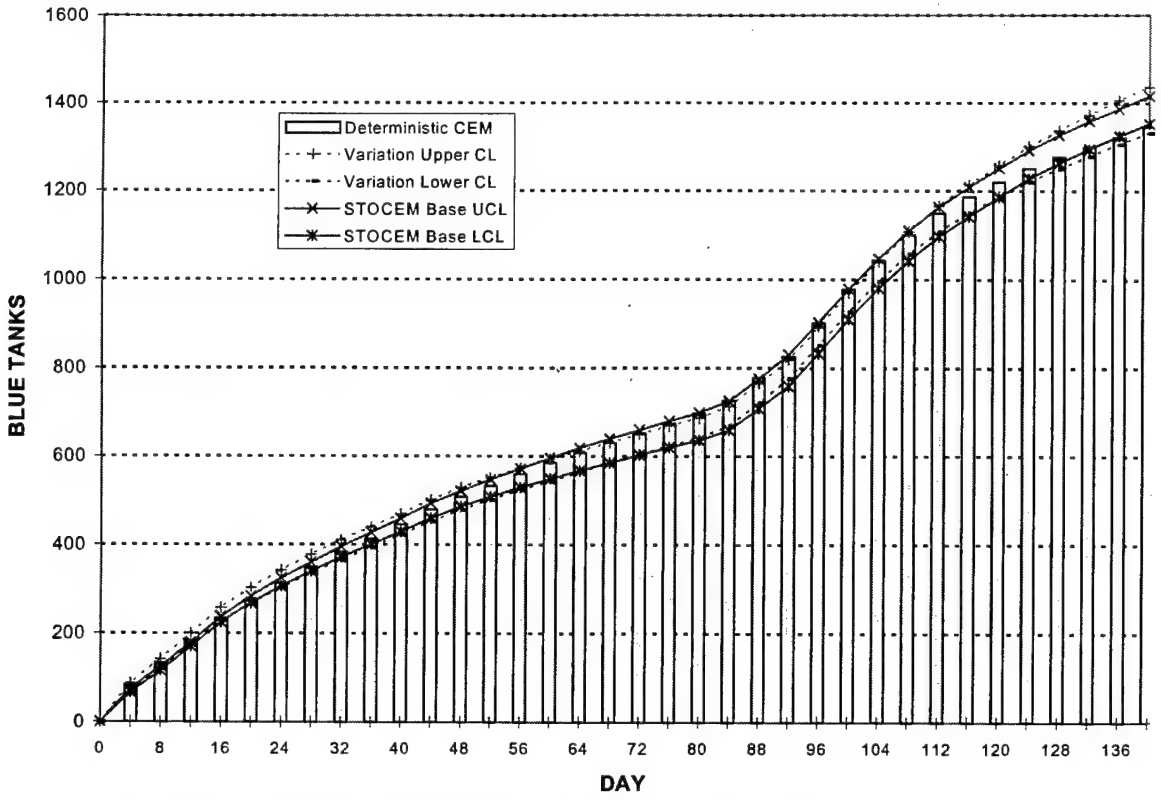

Figure 5-1. Cumulative Permanent Losses of Blue Tanks, SRA-05 NEA

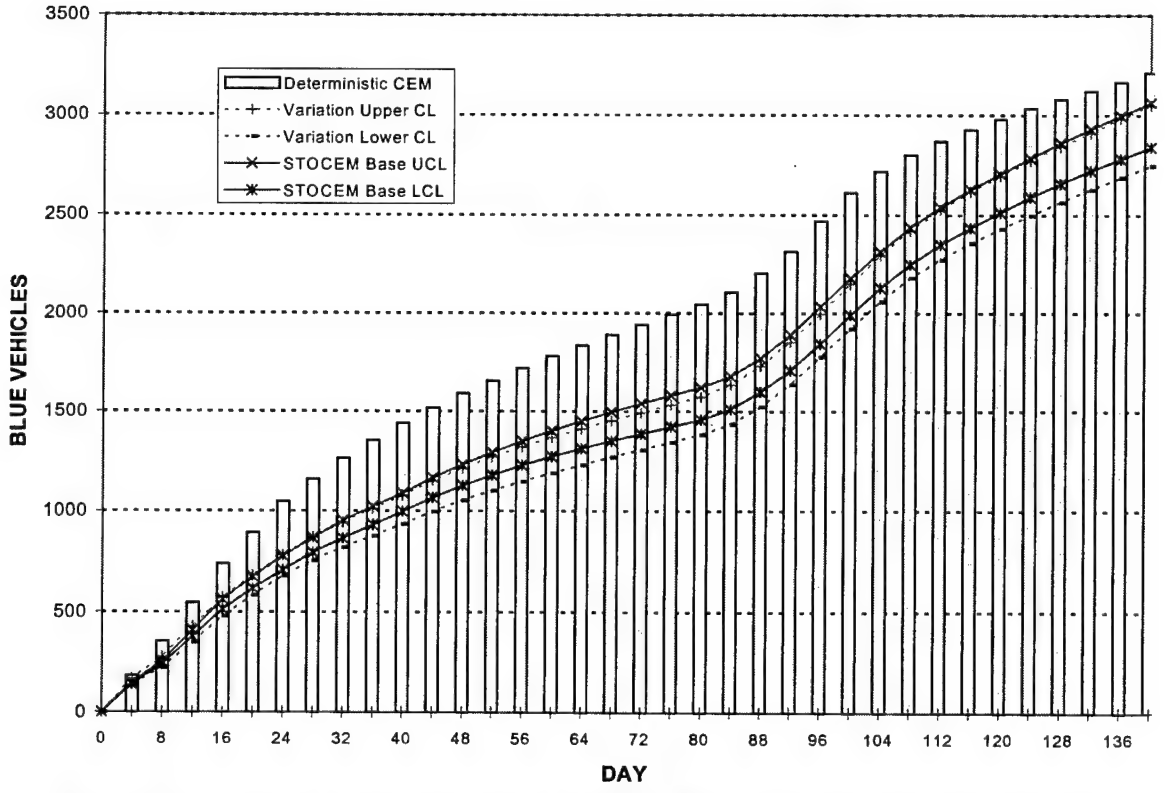

Figure 5-2. Cumulative Permanent Losses of Blue Light Armor, SRA-05 NEA

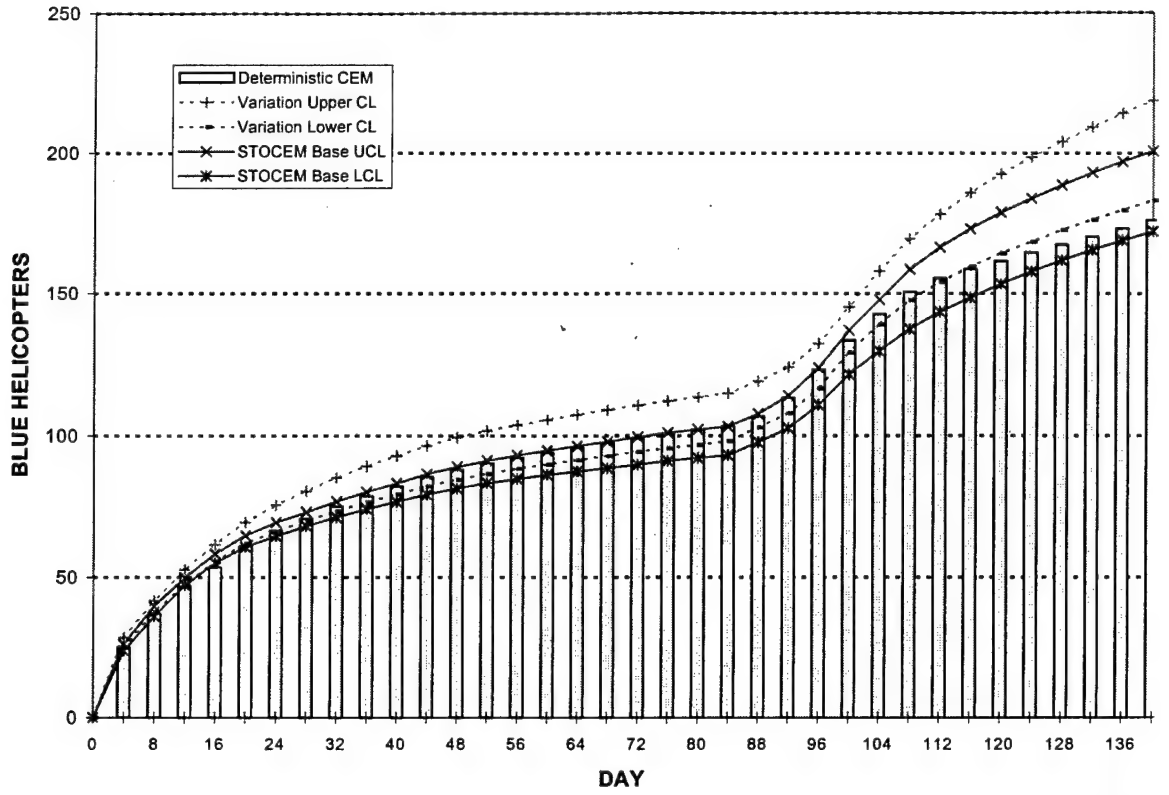

Figure 5-3. Cumulative Permanent Losses of Blue Combat Helicopters, SRA-05 NEA

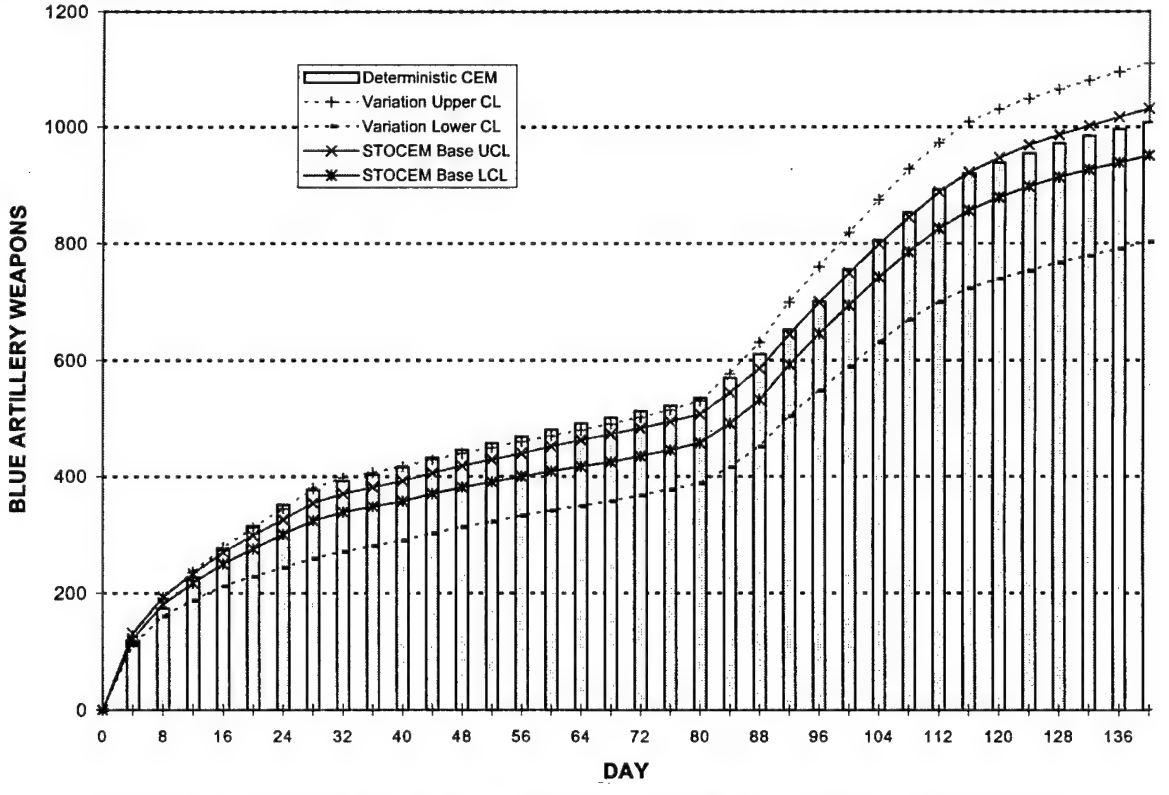

Figure 5-4. Cumulative Permanent Losses of Blue Artillery, SRA-05 NEA

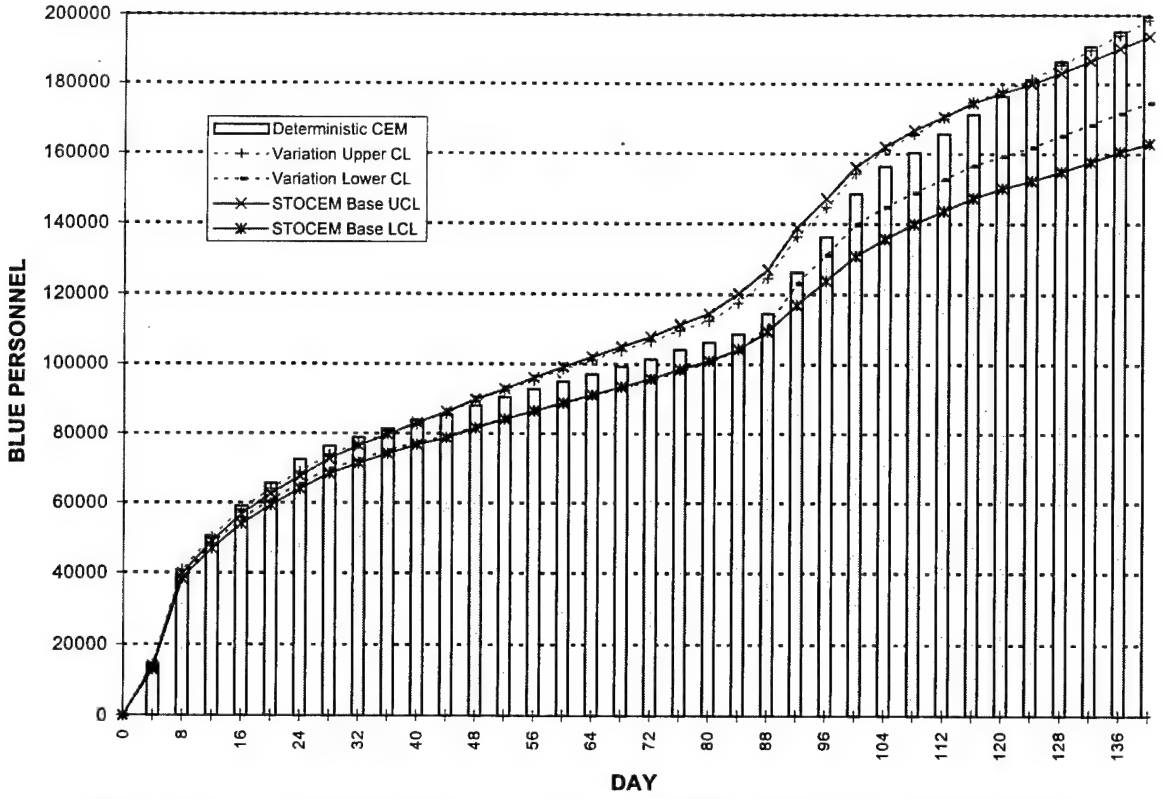

Figure 5-5. Cumulative Permanent Losses of Blue Personnel, SRA-05 NEA

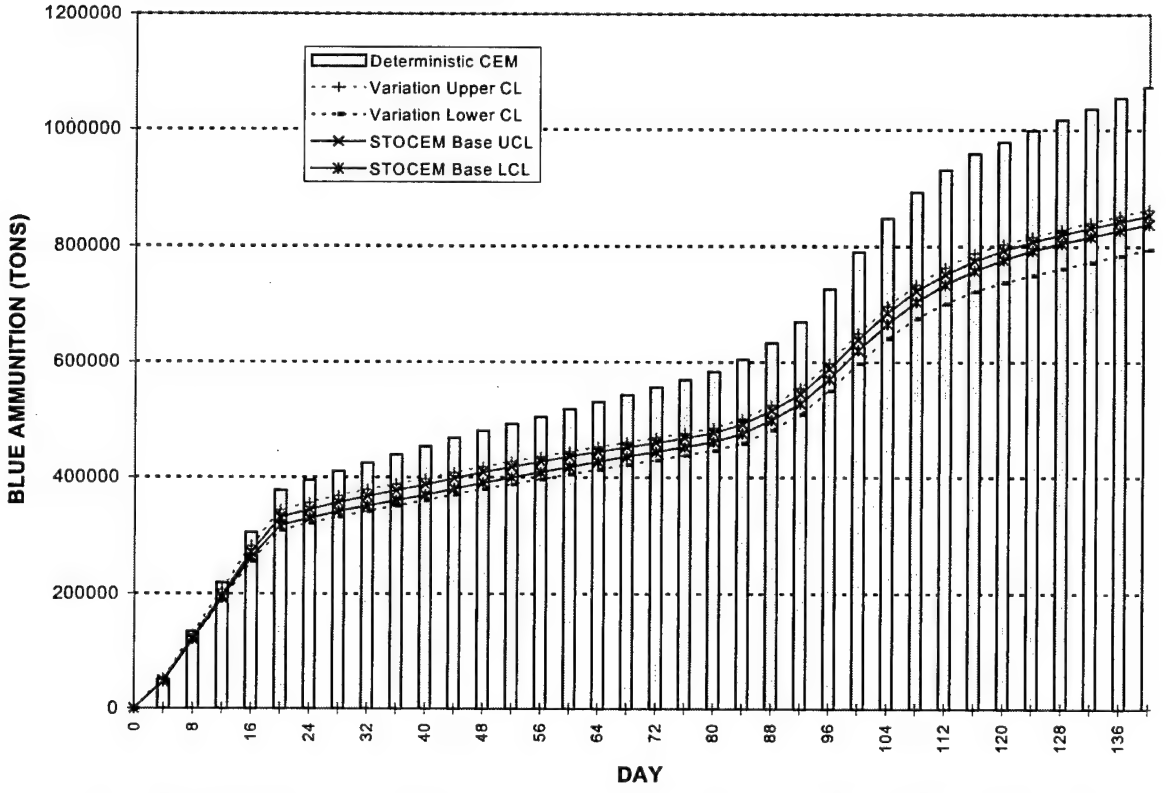

Figure 5-6. Cumulative Consumption of Blue Ammunition, SRA-05 NEA

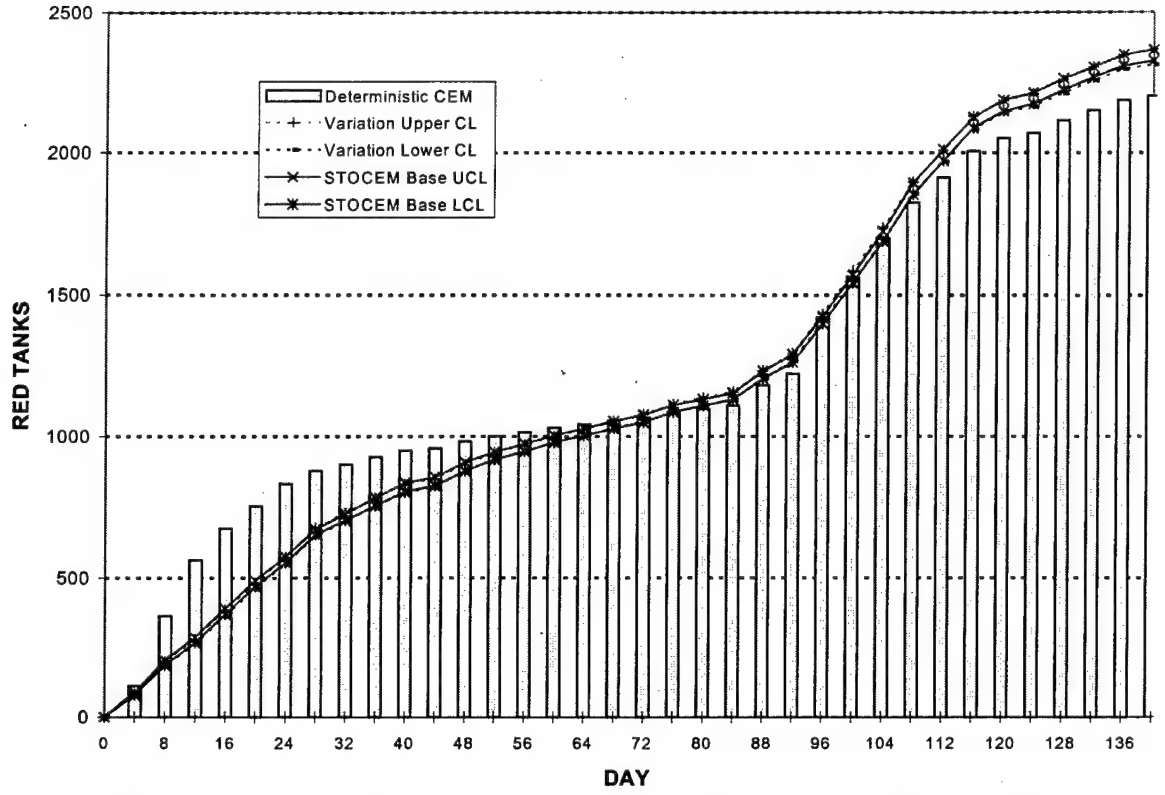

Figure 5-7. Cumulative Permanent Losses of Red Tanks, SRA-05 NEA

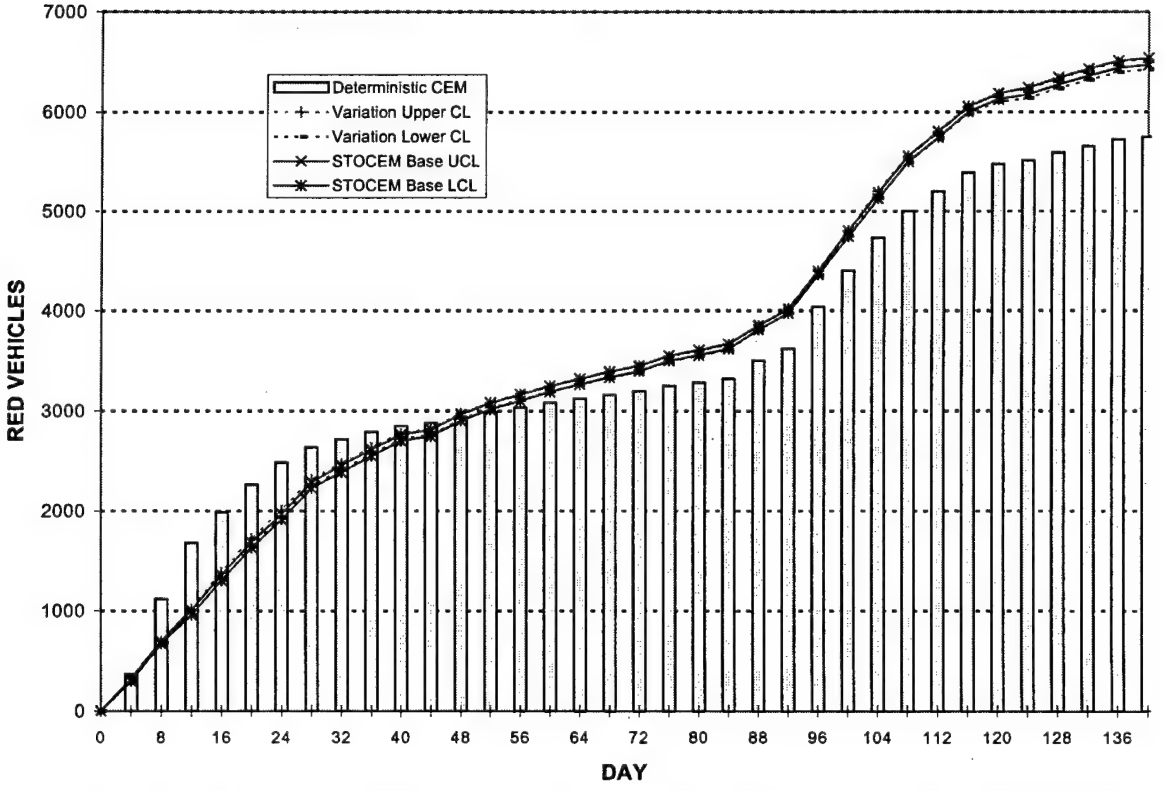

Figure 5-8. Cumulative Permanent Losses of Red Light Armor, SRA-05 NEA

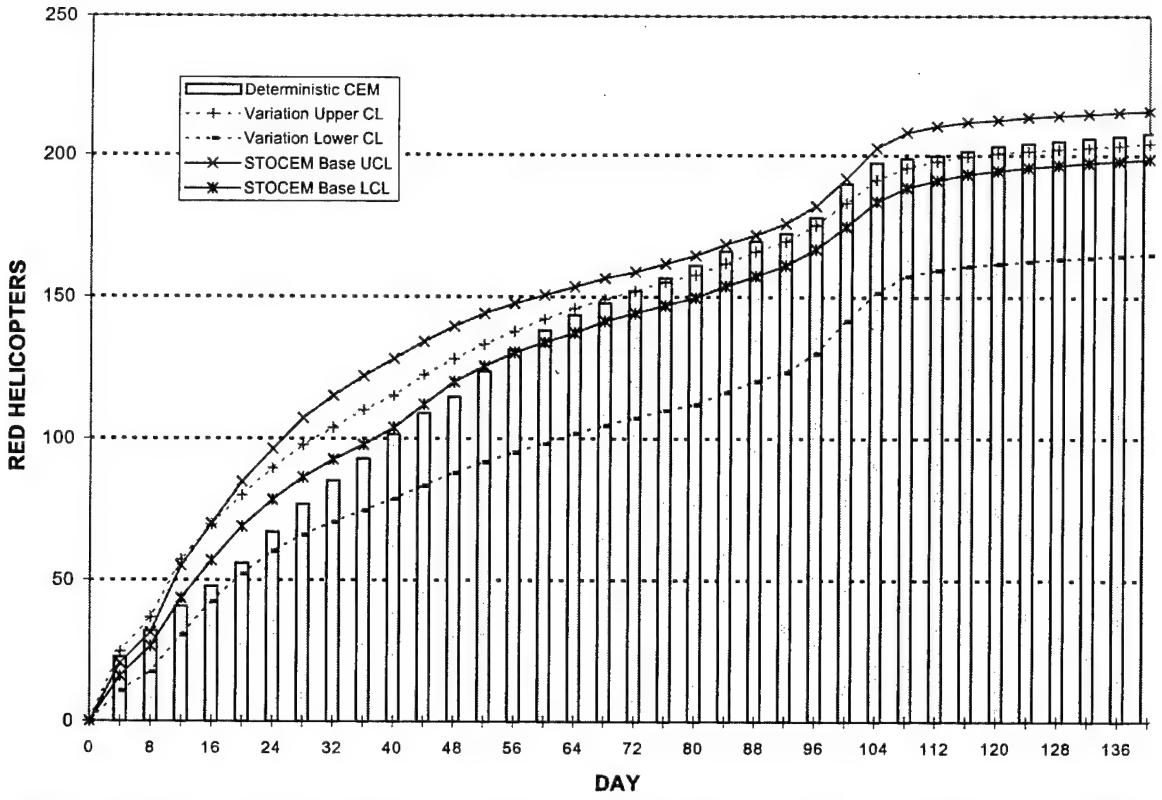

Figure 5-9. Cumulative Permanent Losses of Red Combat Helicopters, SRA-05 NEA

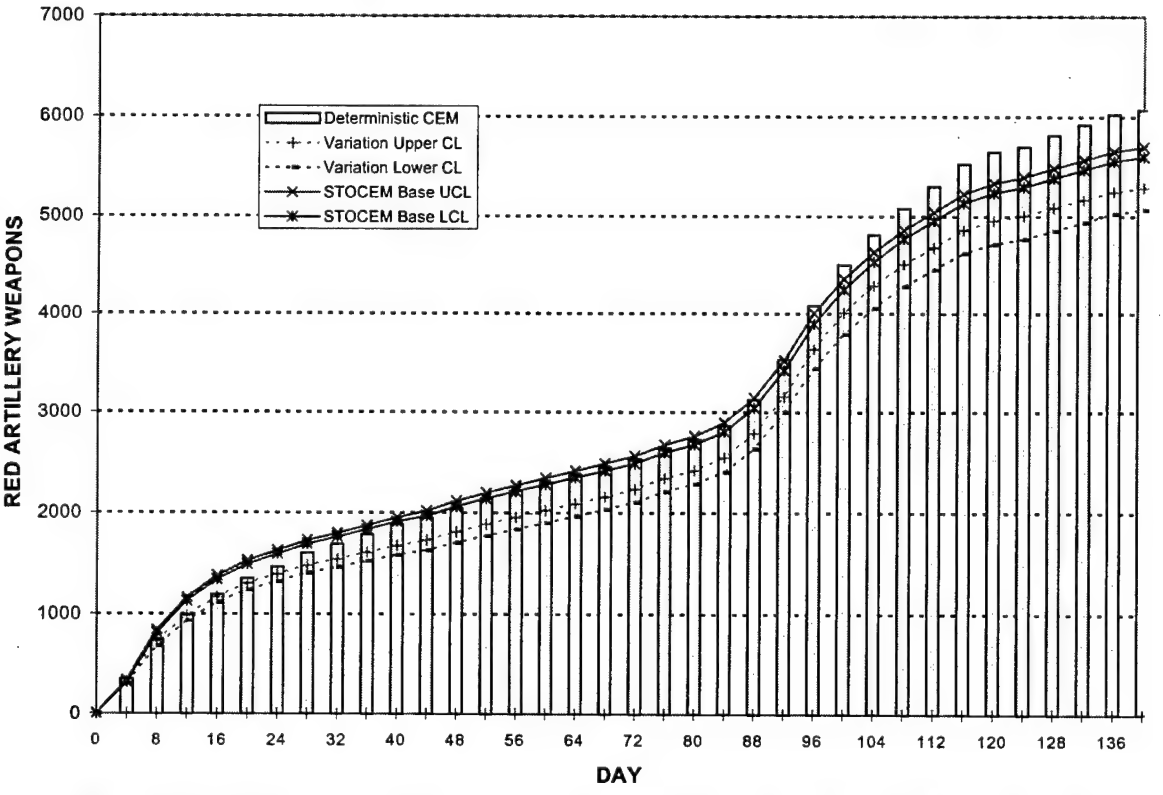

Figure 5-10. Cumulative Permanent Losses of Red Artillery, SRA-05 NEA

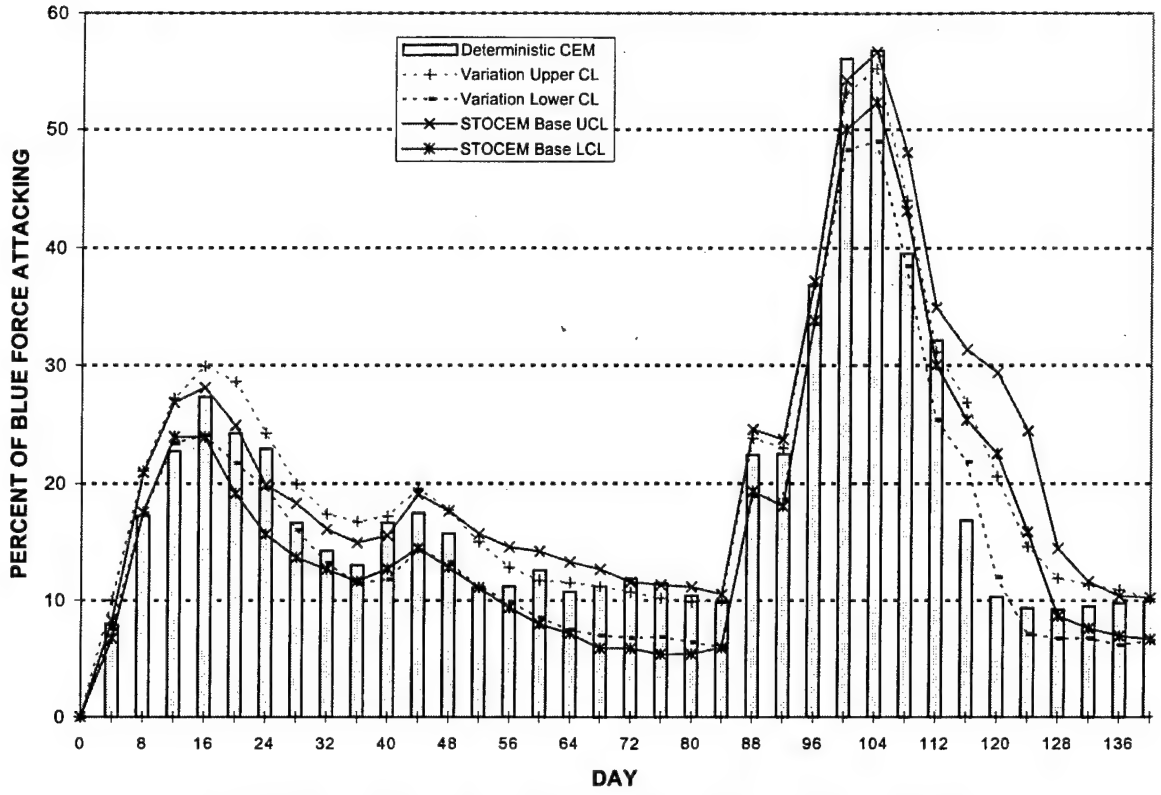

Figure 5-11. Frequency (%) of Blue Attacks, SRA-05 NEA

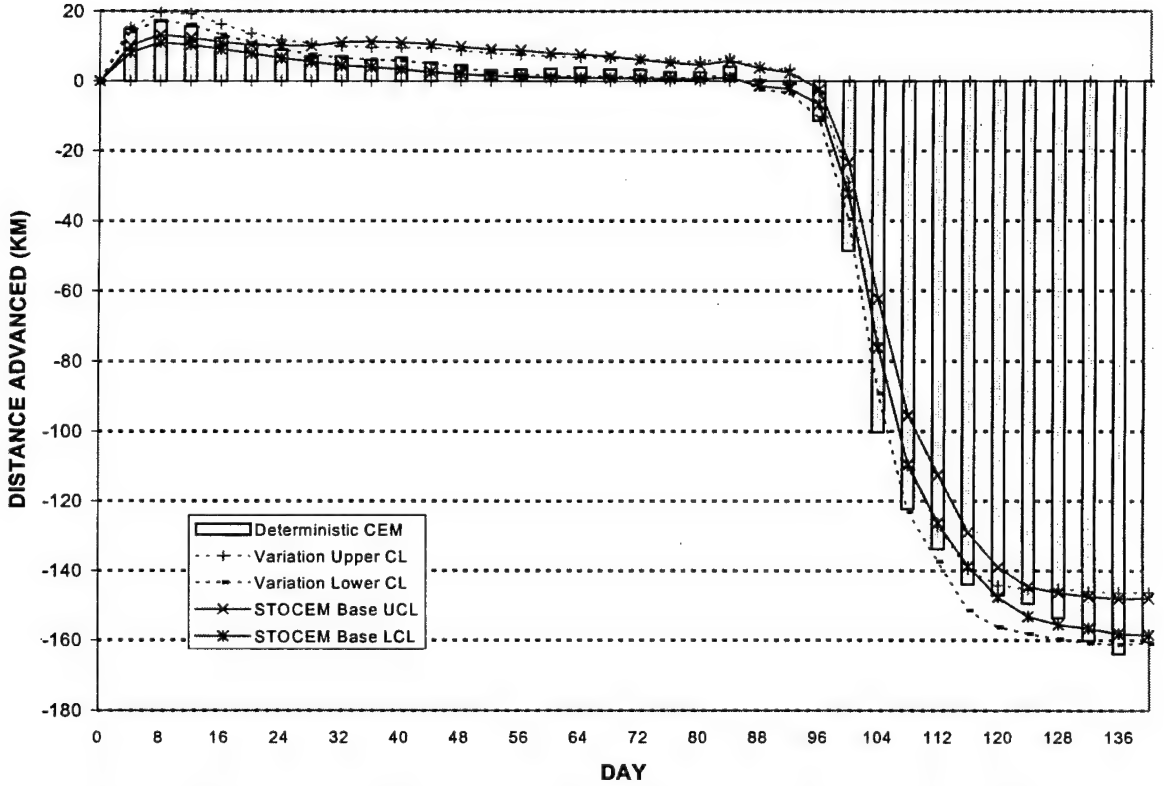

Figure 5-12. Cumulative Average Red Advance per Sector, SRA-05 NEA

b. In Figure 5-12 a negative value indicates a net gain of terrain by Blue forces. We note that the variability among STOCEM replications, as indicated by the distance between lower and upper confidence limits, is greater in the STOCEM variation case than in the STOCEM base case results for losses of Blue light armor, Blue artillery, and Red helicopters and for consumption of Blue ammunition. Variability is greater in the STOCEM base case than in the variation case for Blue personnel losses. Deterministic CEM is generally closer to the mean (the midpoint of confidence limits) of the variation case than to the mean of the STOCEM base case for losses of Blue personnel and for cumulative FEBA movement. Deterministic CEM is generally closer to the mean of the STOCEM base case than to the mean of the variation case for losses of Blue light armor, Blue helicopters, and Red artillery and for consumption of Blue ammunition.

c. Figure 5-13 depicts on a map the FEBA location after 8 days of the simulated campaign for deterministic CEM (the dashed line), the average of the STOCEM base case (the white line), and the average of the STOCEM variation case (the solid black line). D+8 is on average the period of maximum advance by Red, as indicated by Figure 5-12 above. We observe that the D+8 Red forces advance farther in deterministic CEM than in the STOCEM base case average, and Red advances farthest in the average of the STOCEM variation case.

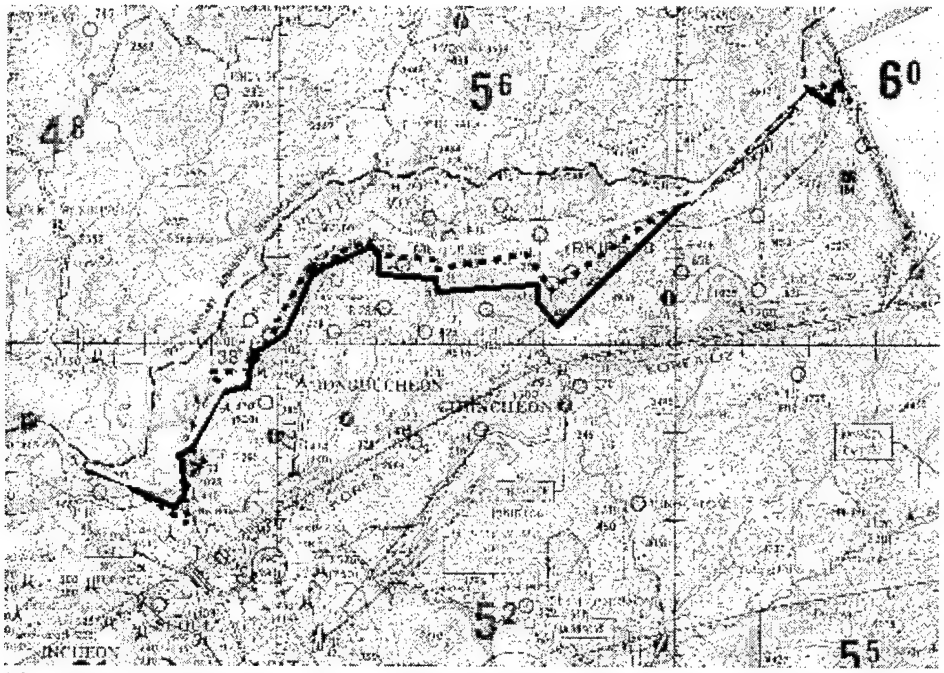

Figure 5-13. FEBA Location at D+8, SRA-05 NEA CEM (Dashed Line), STOCEM Base (white line), STOCEM Variation (solid black line)

5-3. RESULTS OF STOCEM VARIATION, SWA

a. Figures 5-14 to 5-24 show the STOCEM variation case results for selected MOE compared with the SRA-05 SWA STOCEM base case simulation and with CEM results. In each figure for every 4-day time period, the bar height shows the deterministic CEM outcome. The solid lines denote the upper and lower limits of the confidence intervals whose midpoint is the mean of the STOCEM base case replications, as in Figures 4-12 to 4-22. The dashed lines denote the upper and lower limits of the confidence intervals whose midpoint is the mean of the STOCEM variation case. The 99 percent confidence limits about the STOCEM mean are defined as in paragraph 2-2d above. In Figure 5-24, negative values indicate a net gain of terrain by Blue.

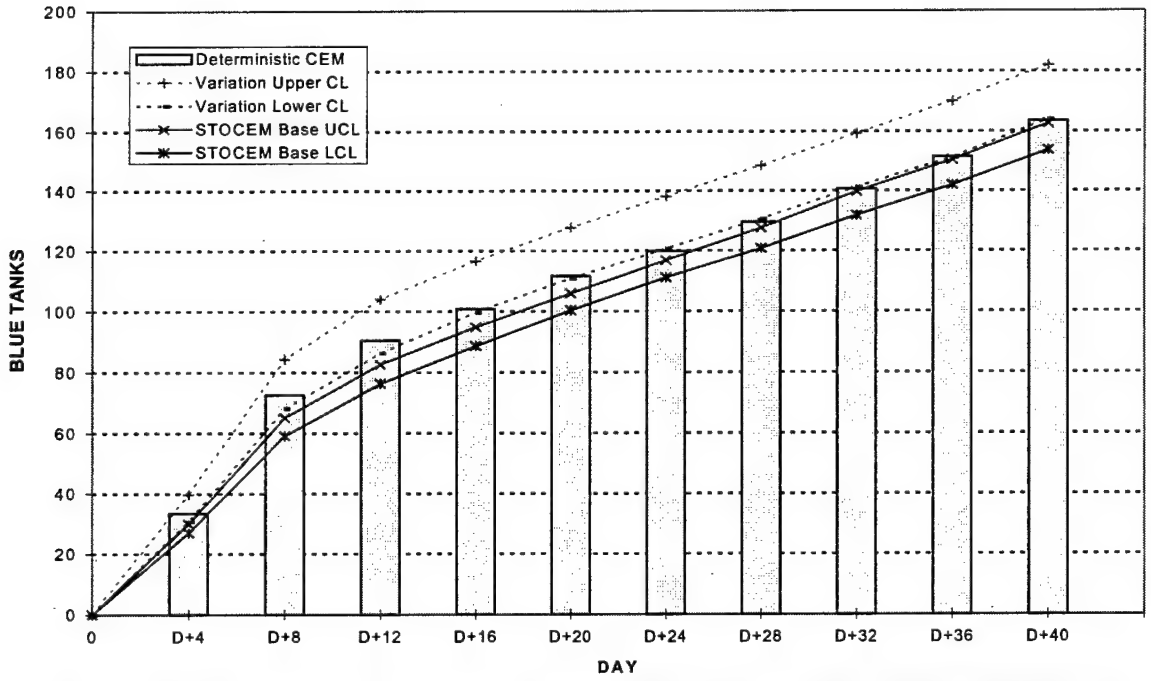

Figure 5-14. Cumulative Permanent Losses of Blue Tanks, SRA-05 SWA STOCEM

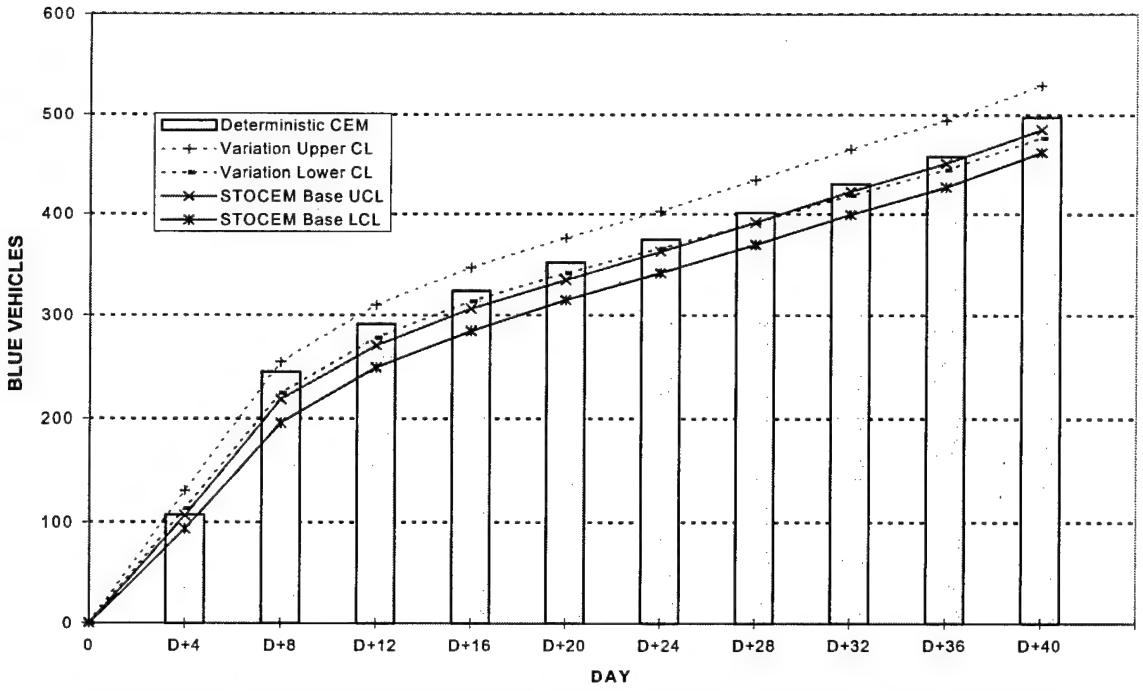

Figure 5-15. Cumulative Permanent Losses of Blue Light Armor, SRA-05 SWA

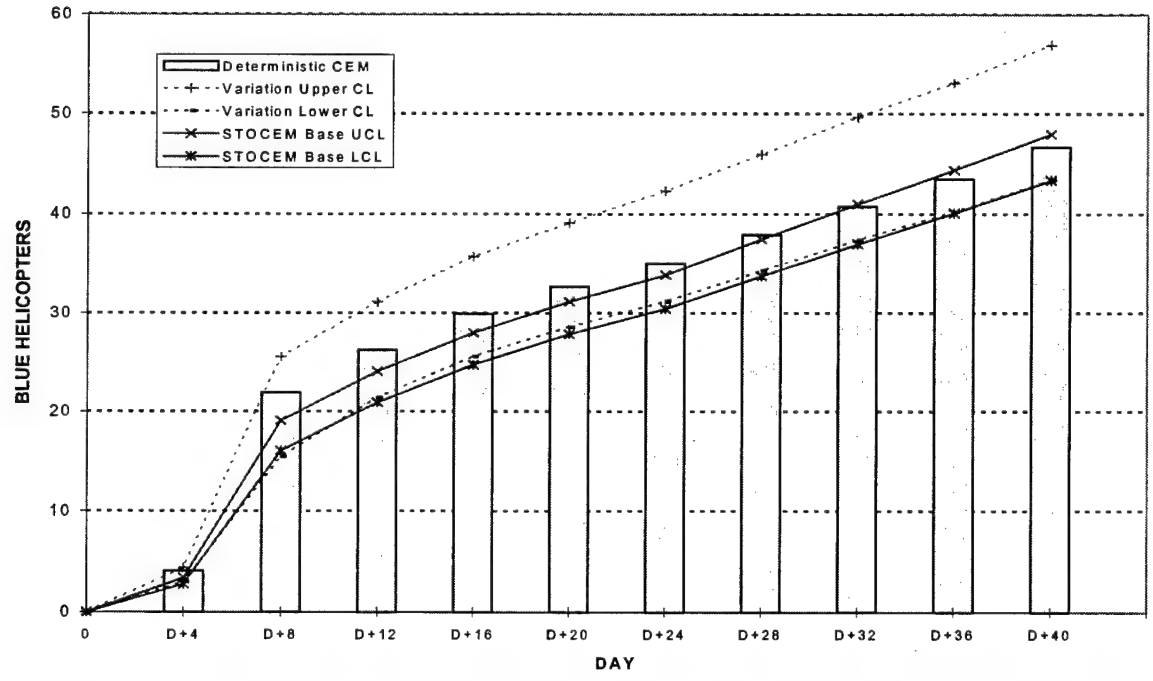

Figure 5-16. Cumulative Permanent Losses of Blue Combat Helicopters, SRA-05 SWA

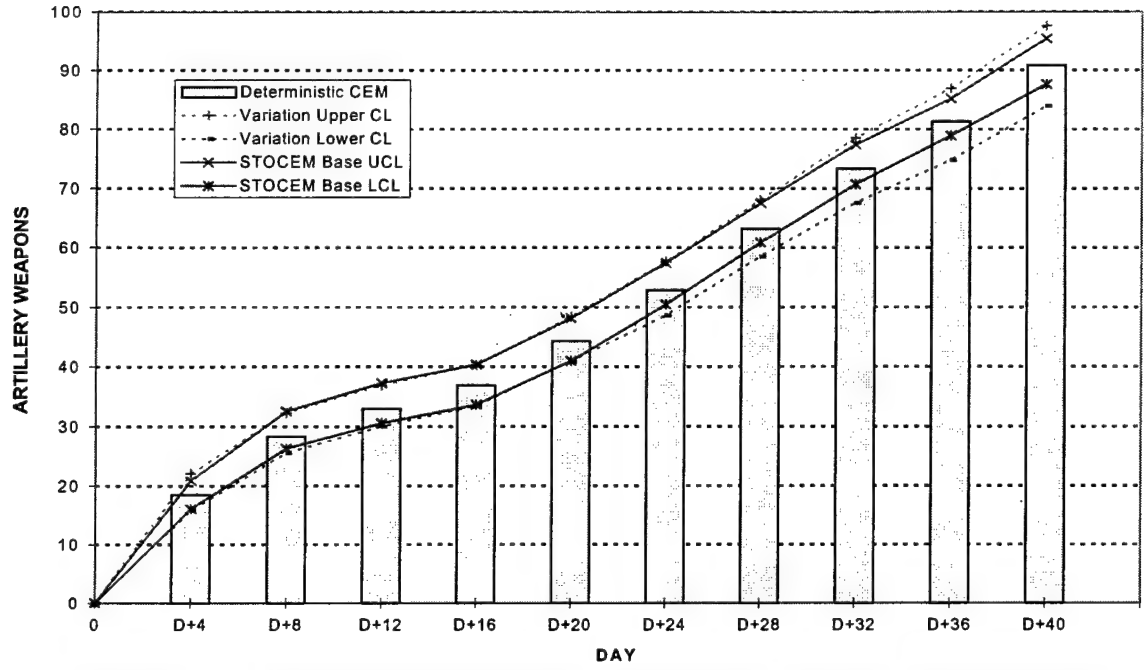

Figure 5-17. Cumulative Permanent Losses of Blue Artillery, SRA-05 SWA

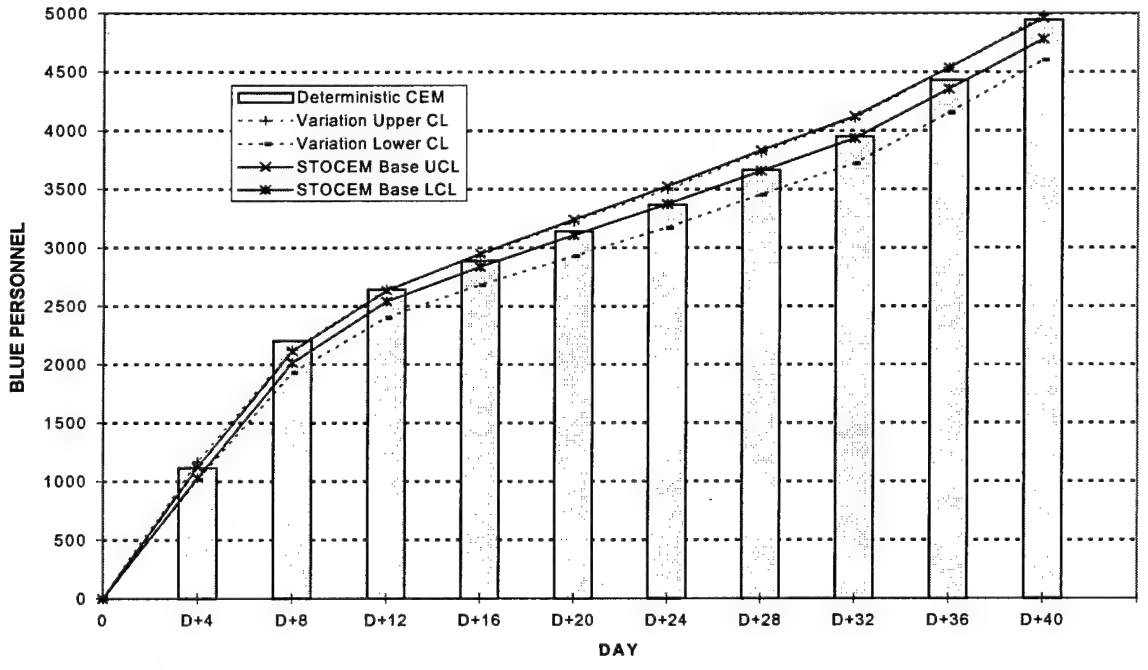

Figure 5-18. Cumulative Permanent Losses of Blue Personnel, SRA-05 SWA

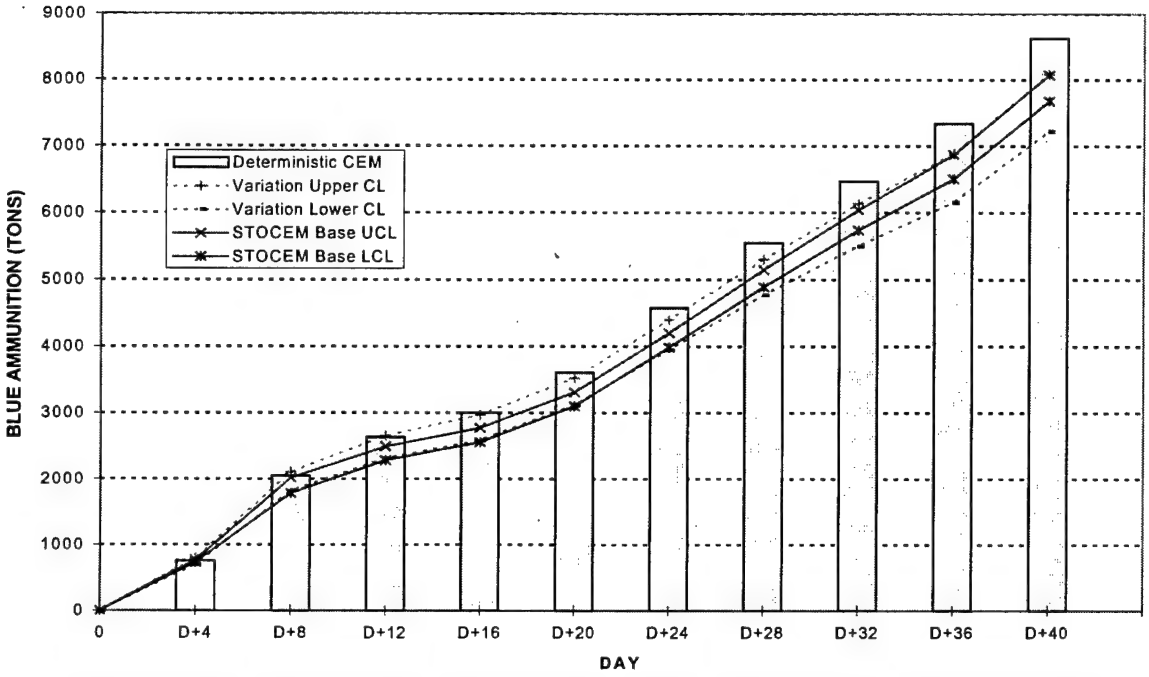

Figure 5-19. Cumulative Consumption of Blue Ammunition, SRA-05 SWA

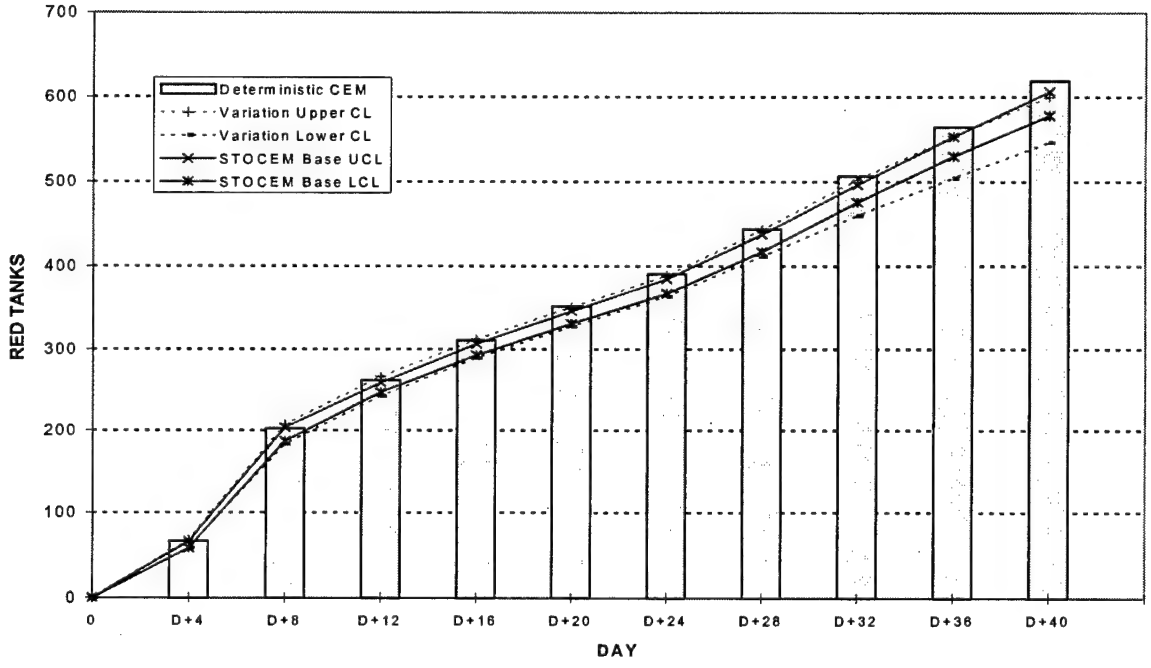

Figure 5-20. Cumulative Permanent Losses of Red Tanks, SRA-05 SWA

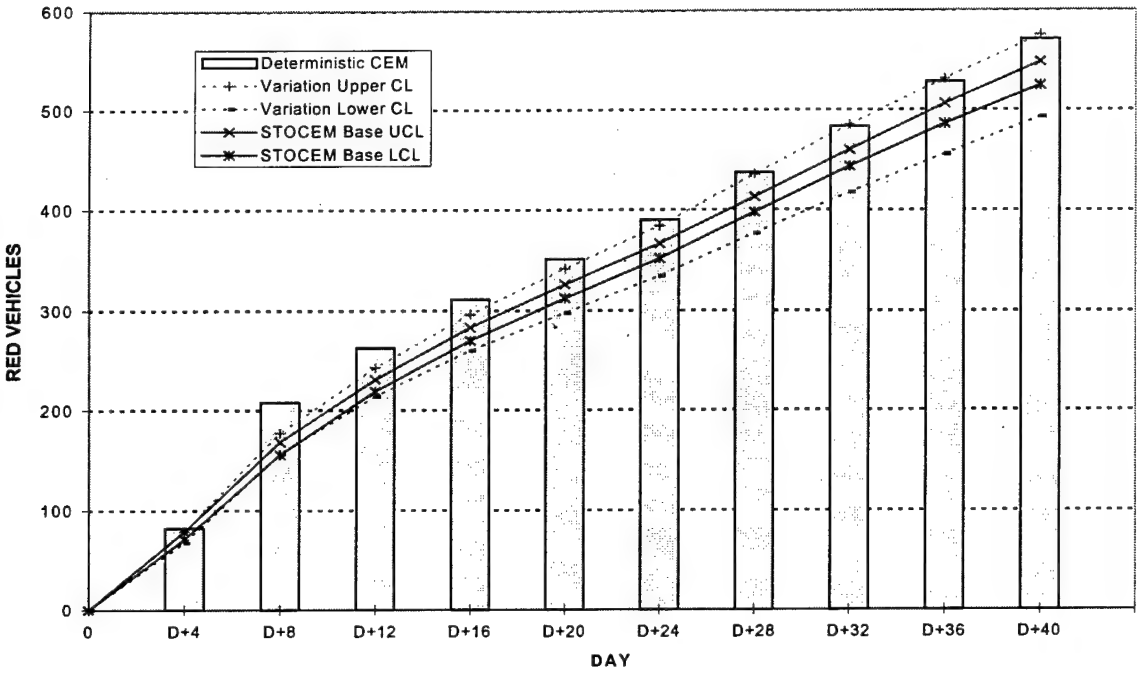

Figure 5-21. Cumulative Permanent Losses of Red Light Armor, SRA-05 SWA

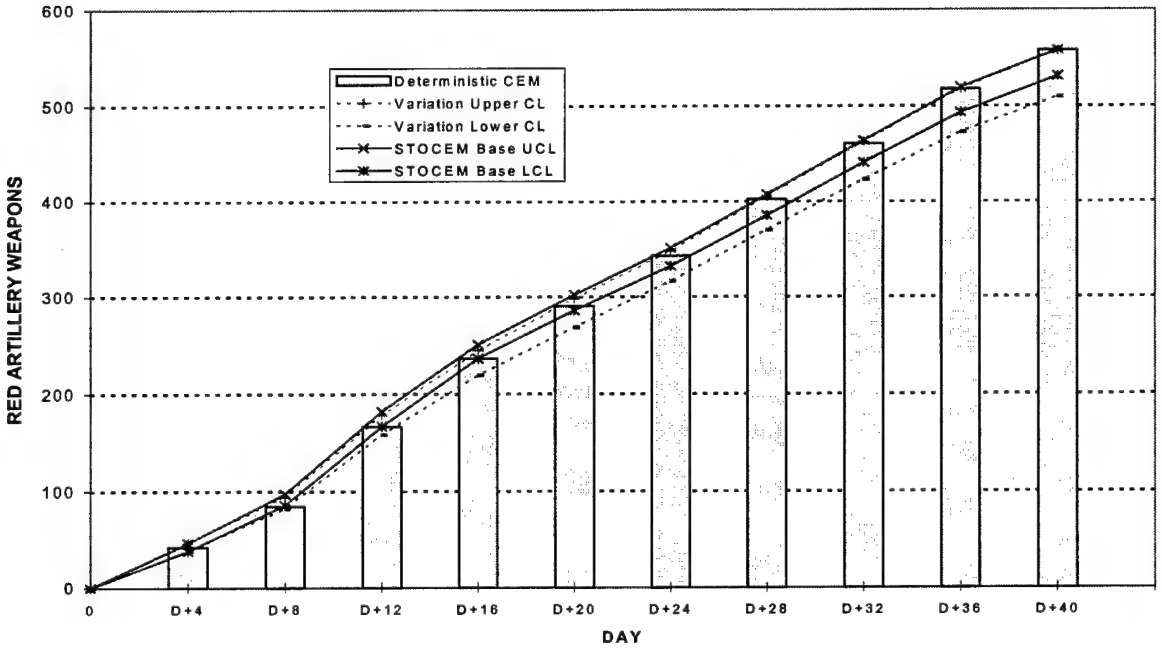

Figure 5-22. Cumulative Permanent Losses of Red Artillery, SRA-05 SWA

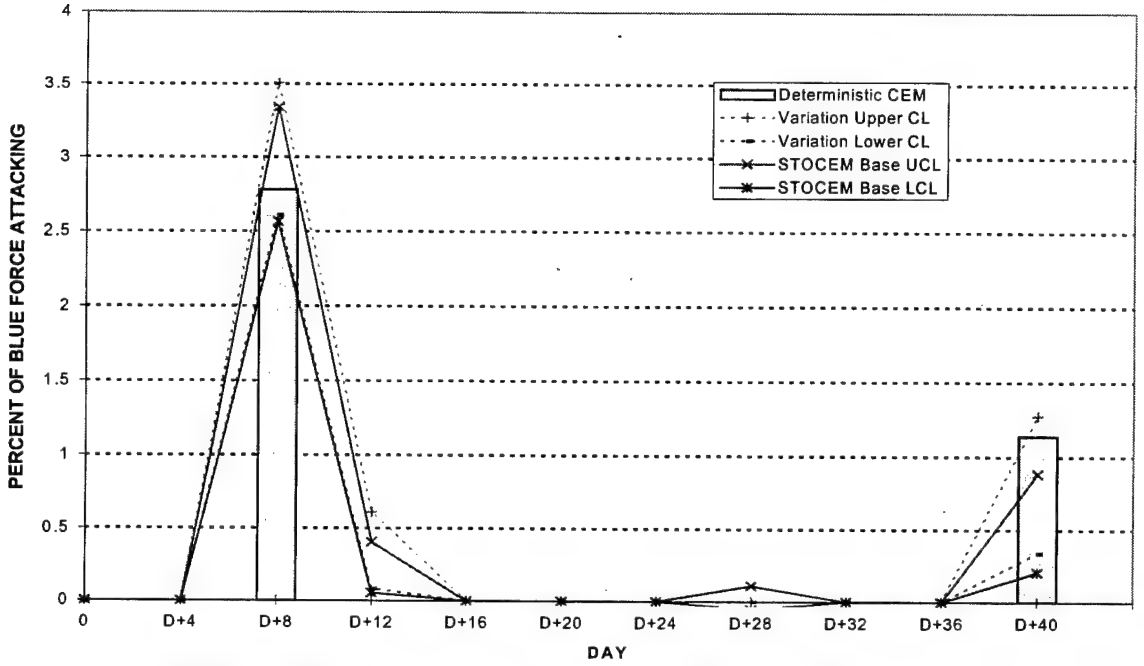

Figure 5-23. Frequency (%) of Blue Attacks, SRA-05 SWA

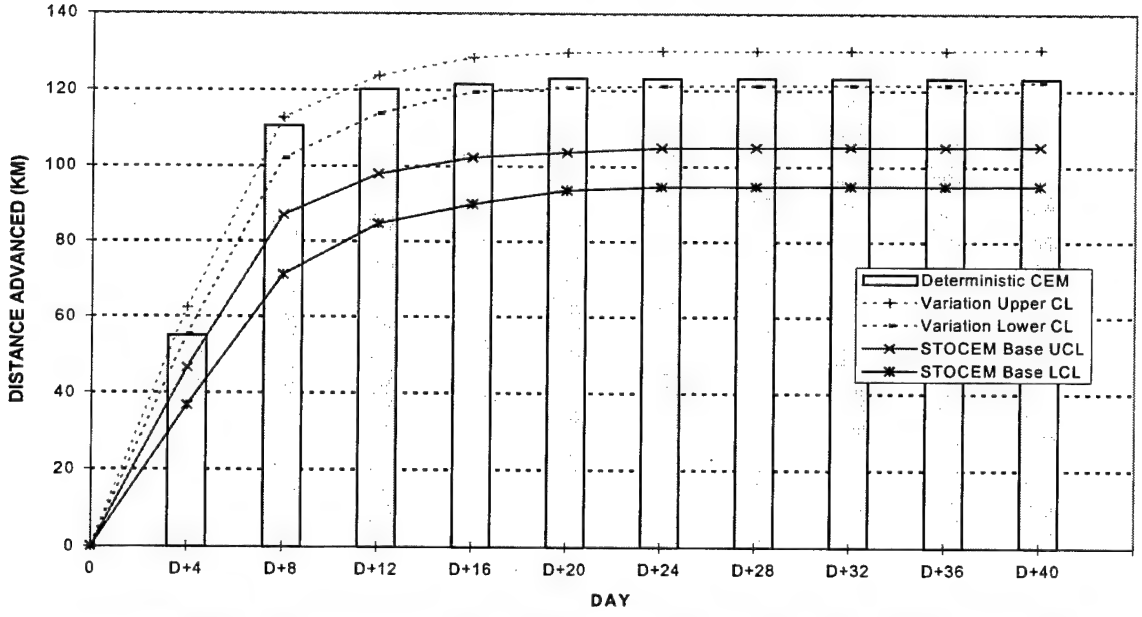

Figure 5-24. Cumulative Average Red Advance Per Sector, SRA-05 SWA

b. Figures 5-14 to 5-24 show that for all the categories of losses and ammunition examined, the STOCEM variation case has greater variability among replications than does the STOCEM base case. It is evident from Figure 5-24 that the FEBA movement in deterministic CEM is considerably closer to the results of the STOCEM variation than to the STOCEM base case results.

c. Figure 5-25 shows the D+40 FEBA location for the average of the STOCEM base case (solid line), the deterministic CEM (vertical bars), and the average of the STOCEM variation case (dashed line). The horizontal axis indicates the CEM /STOCEM minisectors of the SWA theater, with the western side to the left. In Figure 5-25, negative values indicate an advance by Red forces. The minisectors between 301 and 500 are not occupied by either side. This figure shows that Red forces gain more terrain by D+40 in CEM than in the STOCEM base case average, in the western sectors. The D+40 FEBA location of the STOCEM variation case is very close to deterministic CEM's for minisectors 1 to 200, but Red forces gain more terrain in the STOCEM variation case than in CEM on minisectors 201 to 300.

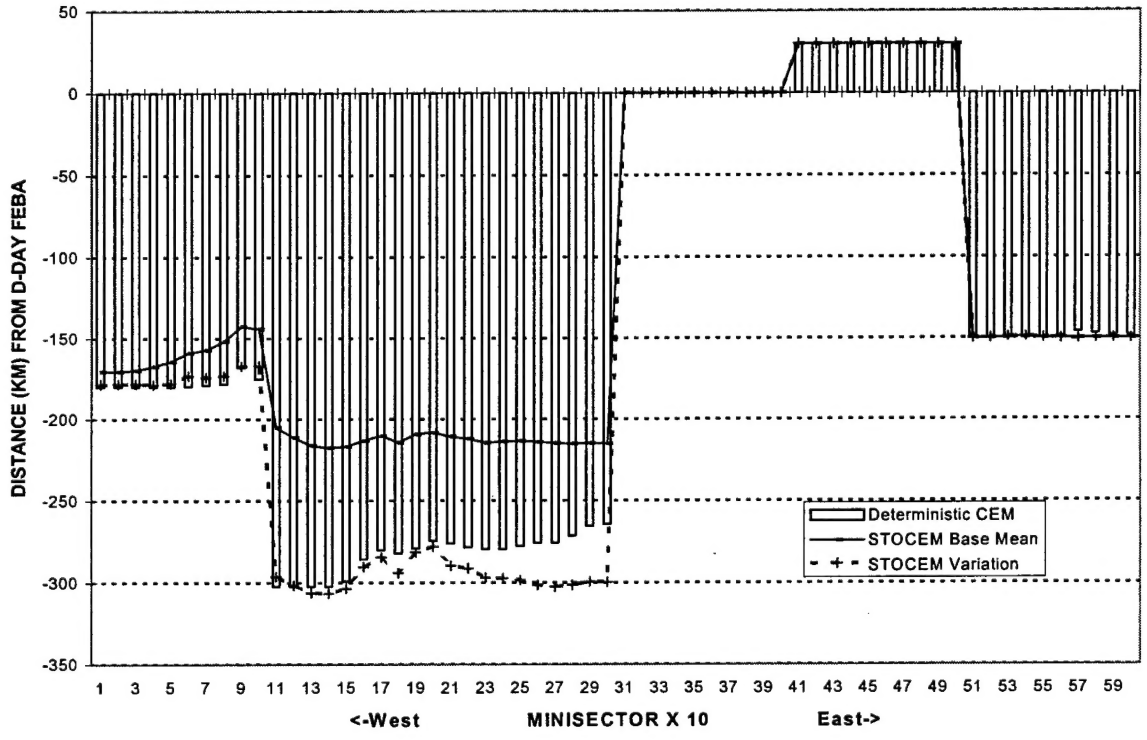

Figure 5-25. D+40 FEBA Location, SRA-05 SWA STOCEM Base

APPENDIX A

REQUEST FOR ANALYTICAL SUPPORT

PART 1

REQUEST FOR ANALYTICAL SUPPORT

1. Performing Directorate/ Division: OS			**2. Account Number:**
3. Type Effort (Enter one): [R] **Mode (Contract=C)** [ ]	S - Study Q - QRA P - Project R - RAA M - MMS	**4. Tasking (Enter one):** [V]	F - Formal Directive I - Informal V - Verbal
5. Title: Stochastic Simulation Analysis - 2005			
6. Acronym: SSA05	**7. Date Request Received:** 04/15/97		**8. Date Dúe:** 07/15/97
9. Requester/Sponsor (i.e., DCSOPS): CAA			**10. Sponsor Division (i.e., SSW, N/A)** N/A
11. Impact on Other Studies, QRA, Projects, RAA:			
12. Product Required: Memorandum Report			
13. Estimated Resources Required:	a. Estimated PSM: 3.5		b. Estimated Funds:
c. Models Req'd: CEM, STOCEM			d. Other:

14. Objective(s)/Abstract:
Objective is to simulate using the Stochastic Concepts Evaluation Model (STOCEM) a base case conventional campaign from each of the northeast Asia (NEA) and southwest Asia (SWA) theaters, and to compare the results of STOCEM with the deterministic Concepts Evaluation Model (CEM) results of Support Force Requirements Analysis - 2005 (SRA-05).

15. Study Director/POC:	Last Name: Johnson	First: Ralph	Date: 04/15/97
	Signature: Ralph E Johnson		Phone#: 295-1542

GO TO BLOCK 20 *If this is A STUDY*. See Tab C of the Study Directors' Guide for preparation of a Formal Study Directive.

PART 2

16. Background/Statement of Problem*: The development of the STOCEM was initiated in 1991. Performance of STOCEM has been demonstrated and tested, most recently insimulations of the 1944 Ardennes Campaign. STOCEM can provide estimates of variability and confidence intervals surrounding a simulation outcome.

17. Scope of Work*: Prior to executing STOCEM, inputs to CEM for the SRA-05 base case of each theater will be obtained. The individual replications of the Combat Sample Generator (COSAGE) will be processed by the Reduction and Linkage Phase 1 (RALPH) program for each posture of each theater. STOCEM will be executed for SWA and NEA. STOCEM results will be compared with SRA-05 CEM results. The comparisons will be documented.

18. Issues for Analysis*: How large is the variability in the results of STOCEM for the SRA-05 scenario? To what extent are the results of STOCEM consistent with the CEM results of the SRA-05 scenario?

19. Milestones/Plan of Action*: 15 May: CEM inputs, including individual replications of COSAGE, prepared.
30 May: STOCEM simulations completed.
10 Jul: Final ARB
14 Jul: PRB of memorandum report

20. Division Chief Concurrence:	Wallace W. Chandler	Date: 15 Apr 97
21. Sponsor (COL/DA Div Chief) Concurrence:		Date:

22. Sponsor Comments*:

CAA Form 233 (1 May 95) * Continue on separate sheet Previous editions Obsolete

APPENDIX B

REFERENCES

1. Concepts Evaluation Model IX (CEM IX), Volume II - User's Handbook, CAA-D-85-1, US Army Concepts Analysis Agency, Bethesda, MD, revised December 1995

2. Stochastic Concepts Evaluation Model (STOCEM), CAA-TP-91-6, US Army Concepts Analysis Agency, Bethesda, MD, August 1991

3. Stochastic Concepts Evaluation Model - Phase II (STOCEM-Phase II), CAA-TP-92-2, US Army Concepts Analysis Agency, Bethesda, MD, June 1992

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5. Ardennes Campaign Simulation (ARCAS), CAA-SR-95-8, US Army Concepts Analysis Agency, Bethesda, MD, December 1995

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7. STOCEM Investigation of COSAGE Sampling (SICS), CAA-MR-97-44, US Army Concepts Analysis Agency, Bethesda, MD, July 1997

8. Rates of Advance in Historical Land Combat Operations, CAA-RP-90-1, US Army Concepts Analysis Agency, Bethesda, MD, June 1990

APPENDIX C

CONTRIBUTORS

C-1. TEAM

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c. Contributor

Mr. Walter J. Bauman

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